The Physical and Geochemical Controls on Heavy Metal Cycling in Mangal Sediments, Wynnum, Brisbane.

by

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ABSTRACT

Mangroves in Australia are recognised as having considerable environmental and economic value and as such are accorded legislative protection by state governments. However, despite this recognition and protection, mangrove forests and adjacent areas are still being used as dumping sites for sewage effluent and solid refuse. This study investigates a site at Wynnum, Brisbane, where mangroves provide a barrier between a source of metallic pollutants and the sea; abundant solid metallic refuse is also scattered through the mangrove forest.

Chemical analyses (for Cu, Cd, Pb, Zn, Hg, Cr, Ni, Sn and Fe) of sediments and waters within the mangrove forest and from adjacent salt marsh reveal elevated metal loads and suggest that metals are entering the mangrove ecosystem from the tip by surface runoff and via groundwater. The mangroves form an effective baffle to tidal current and wave action that promotes the accumulation of fine grained organic matter-rich sediment, within and shoreward of the mangrove forest; this sediment in turn provides provides a suitable habitat for large populations of sulphate reducing bacteria. Direct metal adsorption onto the fine sediment, complexing with organic matter in the sediment, and the formation of insoluble sulphides by reaction with bacterially generated sulphide, all contribute to the trapping of metals in and near the mangrove forest. The fine sulphidic mangal sediments make the major contribution to the biogeochemical metal trap but metal uptake by the mangrove plants is also important.

Sediment grainsize is an important control on the vertical distribution of metals in the study area, but the vertical distribution of metals of the sediment column also reflects the position of geochemically distinct horizons which favour either metal trapping (fine grained, neutral to high pH, low Eh horizons) or metal mobilisation (coarse grained, low pH, high Eh horizons). Consequently, the distribution of metals in the sediment column is not fixed because the position of the geochemical horizons can change seasonally in response to changes in rainfall induced ground water influx and depression of the water table during prolonged dry periods. The lateral distribution of metals over the surface of the study area is largely controlled by subtle changes in Eh and pH conditions caused by a combination of biological (e.g., the presence or absence of

an algal cover) and physical factors (e.g., the presence or absence of surface depressions, the frequency of tidal inundation and the extent of seasonal desiccation). The lateral distribution of metals in sediment beneath the surface is largely controlled by proximity to the tip face and lateral variations in sediment grainsize and in the hydrological conditions that influence the position of geochemically distinct horizons.

The findings of this study show that for environments such as the mangrove community at the Wynnum Tip site, it is important to understand the geochemical conditions in the environment before developing management strategies. Because the reduced sulphidic sediment makes such an important contribution to the metal trapping in the mangrove forest, future land management planning for the area will need to ensure that these sediments are not drained and allowed to oxidise. Oxidation, which would be a likely result of draining the sediment, would not only release many of the presently trapped metals but would probably also create the type of problems typically associated with acid sulphate soil formation.

INTRODUCTION

Mangrove ecosystems can be found in all but the most southerly estuaries and harbours of Australia where they provide nursery or breeding grounds for several commercially important species of marine fauna (e.g., Saenger *et al.*, 1977; Hutchings & Saenger, 1987); many mariculture operations are also undertaken in or near mangrove forests. In Australia, recognition of the primary environmental and economic importance of mangrove ecosystems is reflected in the legislative protection accorded to them by state governments but despite this protection many Australian mangrove forests are polluted by metallic and non-metallic anthropogenic wastes. At some sites effluent is discharged directly into the mangroves, at others various solid wastes are dumped among the mangroves and at others a belt of mangroves separates a source of potential pollutants (such as a refuse tip) from adjacent marine or estuarine environments. Observations in urban mangrove forests in eastern Australia show clearly that although scientific awareness of the importance of these forests as a natural resource has increased, the mangroves are still being used extensively as convenient sites for dumping domestic garbage and installing industrial and local government effluent outfalls (e.g., the sewage outfall ca. 1 km north of the tip site, **Fig.** 1).

The case for the protection of mangrove ecosystems as a buffer between sources of metallic pollutants and nearby aquatic ecosystems has been made previously (Harbison, 1981), but there are surprisingly few papers in the scientific literature on the response of mangrove ecosystems to heavy metals. Although some work on the reaction of mature mangrove plants (Montgomery & Price, 1979; Peterson *et al.*, 1979) and seedlings (Walsh *et al.*, 1979; Thomas & Eong, 1984) to elevated heavy metal loads has been published, most of the work has been carried out overseas and little is known about how Australian

mangrove communities respond to metallic pollutants.

Project Background

The metal load in mangroves at Wynnum, Brisbane, (Fig. 1) was first examined by P. Saenger and D. McConchie in early 1989 as part of a project to compare two potentially polluted mangrove sites and two unpolluted sites; this project had the following aims:

a) to compare heavy metal concentrations in mangroves growing in areas with low metal loads with concentrations in mangroves from areas where high metal loads are likely,
b) to determine whether common species of mangroves show any tendency toward selective metal accumulation in, or exclusion from, particular parts of the plant,
c) to investigate pathways for metal transfer between mangroves and associated sediment, water, and detritivores, and
d) to assess the value of mangrove forests a buffer between marine environments and sources of metallic pollutants.

The Brisbane River was selected by Saenger and McConchie as one of the potentially polluted sites and the Wynnum mangroves were sampled because they are adjacent to a large refuse tip near the Brisbane River and are readily accessible. The Wynnum mangroves were found to contain the second highest metal loads of all sites sampled.

The findings of Saenger and McConchie were subsequently used by the Deputy Leader of the Opposition (now Deputy Premier, T. Burns) as the basis for a series of questions to the Queensland State Parliament seeking to find out how these mangroves were being polluted, who was responsible for the pollution, and why was the government allowing continued pollution of these protected mangroves? As a result of these questions, and the publicity they generated, the Minister of the Environment and Heritage commissioned his

department to investigate the site. The brief Environment and Heritage study reported lower metal concentrations than those found by McConchie and Saenger (D. Neale, Department of Environment and Heritage, Queensland, pers. comm.) largely because sample site selection did not allow for the influence of environmental biogeochemical factors on metal distribution.

The parliamentary questions also resulted in further protection for the mangroves with the early closure of the tip in August 1991 and the declaration of the mangroves as part of the Moreton Bay National Park. In September of 1991, to allay environmental concerns the Brisbane City Council installed a leachate drain to trap tip leachate for disposal as a toxic waste or treatment. No data on the effectiveness of this drain have so far been presented by the council.

Aims and Objectives

This study was designed to obtain a more detailed understanding of chemical processes controlling the accumulation and distribution of heavy metals in the Wynnum mangroves and associated sediments. Processes requiring investigation included the modes of transport of metals from the tip into the mangroves, metal transport mechanisms within the mangal sediments, processes involved in immobilisation and mobilisation of metals in the sediments, and the role of biota in these processes.

This study also was designed to extend the range of metals examined by McConchie and Saenger to include Hg, Cr, Ni, Sn, and Fe with the Cu, Cd, Zn, and Pb previously studied. These metals were chosen after a brief survey of refuse at the tip revealed high volumes of chromium/nickel plated metals tin cans, batteries, paint cans and assorted electrical and electronic components.

Iron was included because iron oxyhydroxides are a major sink for many pollutants and also provide a major transport medium (Salomons & Förstner, 1984; Förstner & Wittman, 1981; Förstner, 1989; McConchie & Lawrance, 1991).

Specific aims of this study are to investigate:

1. the mechanisms of metal immobilisation and/or mobilisation within sediments at the Wynnum site;
2. the roles of biota in the accumulation and/or mobilisation of metals at the Wynnum site;
3. the concentrations of metals entering the mangroves from the tip;
4. the directions of metal movement into and through the mangrove forest;
5. the influence of sediment composition and texture and of local geological factors on metal movement;
6. and the formulation of management strategies for possible remediation of the site.

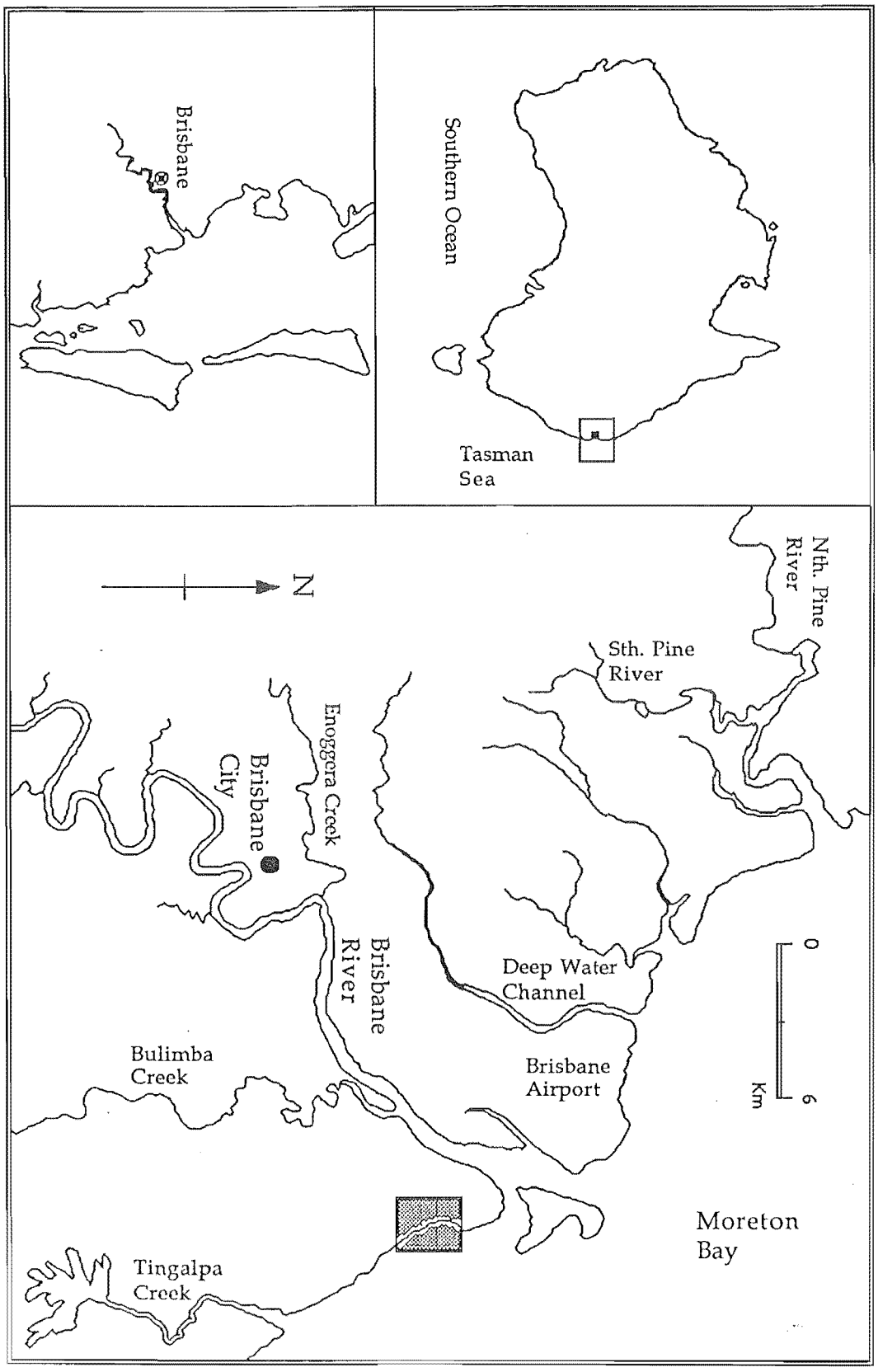


Figure 1 Map showing the location of the Wynnum tip study site (shaded area). The Wynnum sewage outfall is near the northern edge of the shaded area.

SETTING

At the Wynnum site a domestic garbage tip is separated from Moreton Bay by a narrow (ca. 200m wide) belt of mangroves; the mangrove forest and the tip face are separated by a slight depression, roughly 50m wide, which is devoid of any form of macroflora (**Plate** 1). The unvegetated depression is characterised by highly reducing, algae covered, black muds (**Plate** 2), which contain an abundance of metallic and non-metallic refuse; assorted metallic and non-metallic rubbish can also be found scattered throughout the mangrove forest (**Plates** 3, 4, 5, & 6). The lack of vegetation in the depression between the tip face and the mangrove forest is probably drainage induced (P. Saenger, pers. com.). However an extensive oil film on the muds and a strong odour of anthropogenic organic chemicals suggest that the lack of vegetation may also be linked to tip leachates. Both tip leachates and the breakdown of metallic refuse dumped in the mangrove forest are potential sources of heavy metals which may be taken up by the trees or adsorbed by the substrate sediment or both.

Plate 1 Photograph looking seaward from the tip. In the foreground is the area of dead mangroves, which is devoid of any macroflora.

Plate 2 Photograph showing the algae covered black sulphidic muds that occupy the area of dead mangrove. Note the surficial gas bubbles indicating that the water is super saturated with respect to oxygen.

Plate 3 Photograph showing some of the metallic refuse within the mangrove forest. Here the front end of a car has been dumped and allowed to rust away.

Plate 4 Photograph showing some of the metallic refuse within the mangrove forest. Here the rusted remains of a car chassis lie within the mangrove forest.

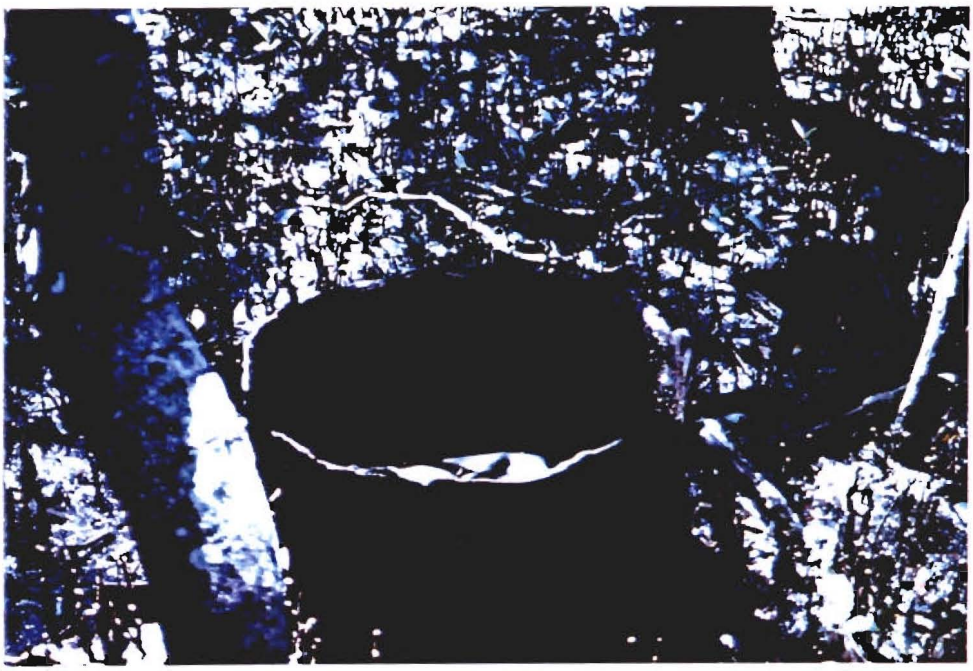


Plate 5 Photograph showing some of the metallic refuse within the mangrove forest. Here the rusted remains of a 44 gallon drum lies within the mangrove forest. The contents of the drum are unknown.

Plate 6 Photograph showing some of the metallic refuse within the mangrove forest. Here part of a potable refrigerator has been dumped within the mangrove forest.

Geographic Setting

The Wynnum refuse tip (latitude 27° 27′ longitude 153° 10′) is on the western edge of the Moreton Bay, Queensland, about 3 km south of the Brisbane River mouth (**Figs**. 1 & 2). To the east, north and northwest the tip is surrounded by salt marsh.

The Wynnum site is roughly 15 km east of the Brisbane City centre (state capital of Queensland) and 6 km southeast of Brisbane airport. Domestic and light industrial refuse from the local area (i.e., the Wynnum/Manly area) was brought to the tip by private individuals; garbage from regular council collections was not dumped at the Wynnum site.

To the southwest of the tip the land surface rises sharply to form low hills and to the west and north the land is low lying and generally of low gradient;

the flat land including the tip, is part of the progradational deltaic surface of the Brisbane River.

About 1.5 km north of the Wynnum site is a major distributary channel of the Brisbane River (the Boat Passage) that separates Fisherman's Island from the mainland (Fig 2). The Port of Brisbane is on the western edge of Fishermans Island just south of the Brisbane Bar (the site for tidal readings).

At the Wynnum site numerous small tidal channels enter the mangroves particularly in the area south of the fisherman's access road (Fig. 2). Tidal channels extend up to about 30 m into the forest and are characterised by a lack of mangrove pneumatophores, an increase in algae cover, and a tendency for channel sediment to be less consolidated than adjacent channel margin deposits. Measurements during this study indicate that channel sediments are more anoxic and have a higher pH than other parts of the mangrove forest.

Filling of the Wynnum tip has lead to some drainage changes and caused most surface waters to drain northward into the salt marsh before moving to the east and into the area of dead mangroves. Despite the blocking of the major southeasterly drainage line by the fisherman's access road, surface waters still migrate in that direction from the salt marsh. Other surface waters from the tip drain to the south and onto the fisherman's access between the two tip cells.

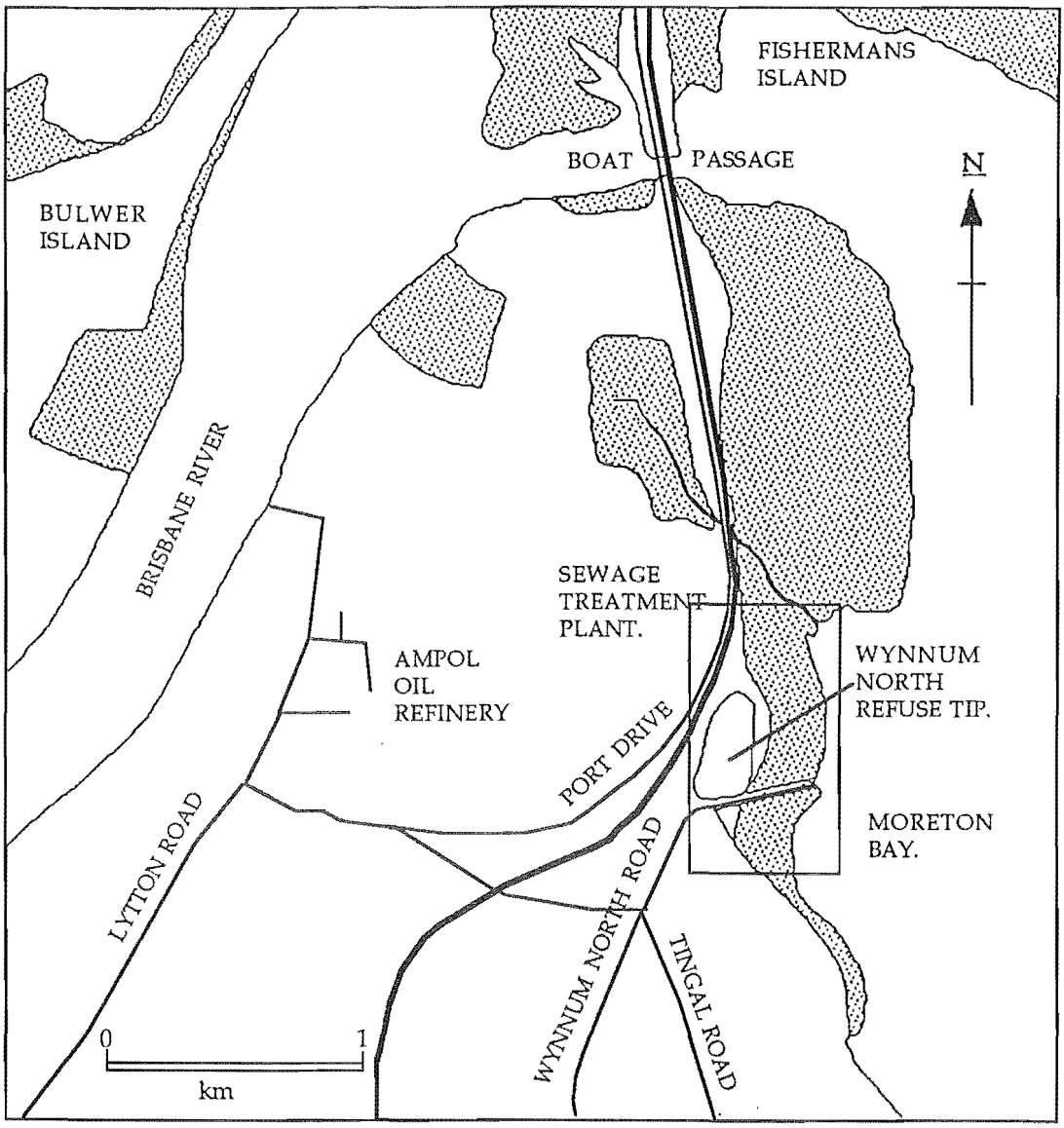


Figure 2 Map showing detail of the Lytton and Wynnum area of Brisbane and the location of the Wynnum North refuse tip. The boxed area is the extent of the study area. Shading represents areas of mangrove forest.

Historical Setting

Since the mid 1800s, when Queensland was opened up for free settlement the construction of port and harbour facilities, marina developments and airport construction have placed pressure on mangrove communities. It is difficult to ascertain the area of mangrove forest that has been cleared in Moreton Bay but it is unlikely that it has exceeded 5% of the total area (Dowling, 1986).

Domestic and minor industrial refuse has been dumped at the Wynnum site since 1925. The first cell, the southern "Old Tip" was open until March 1984 (I. Woods, Manager, Department of Works, Brisbane City Council, pers. comm.)

The Northern Tip is separated into two triangular sections by the fisherman's access road. An agreement with the land holders to the west of the tip site allowed the council to merge the tip with their properties. The merging of the tip and the free hold properties above the original high water mark is said to have eliminated a drainage and mosquito breeding problem (I. Woods, pers. comm.).

The Northern Tip cell had an expected life of eleven years but was closed by the council in June 1991 as a result of both economic and environmental concerns. At the time of closure the council applied 600 mm of cover over the garbage in an attempt to control infiltration of rain water and leachate formation. In September of 1991 the council also laid a leachate drain along the seaward margin of the tip to collect leachate for recirculating or treatment (I. Woods, pers. comm.).

Climatic Setting

The climate of the area is controlled by the seasonal oscillation of the high pressure anticyclone belt in the southern hemisphere. This oscillation results in the southeast of Queensland experiencing two major weather patterns. The first, is controlled by the movement of air from the southwest over the continent during the winter months when the anticyclone belt is at its most northerly position. The second, is controlled by onshore easterly winds in summer when the anticyclone belt is in its most southerly position (Lindacre & Hobbs, 1977; Coordinator General's Department, Queensland, 1974).

The climate of Moreton Bay is classified as Cfa on the Koppen-Geiger system (Koeppe & Long, 1958; Lindacre & Hobbs, 1977; Saenger *et al.*, 1977) or a humid subtropical climatic region (Gentilli, 1972; Koeppe & Long, 1958). This

climate is characterised by high rainfall and humidity during the warmer summer months and drier conditions, with a wide temperature range the winter months.

Temperature

Temperature data for the Wynnum site are assumed to be very similar to data for Brisbane Airport, 3 km to the northwest (**Fig.** 1). **Table** (1) shows temperature data for Brisbane Airport for 1991 and averages for 1949 - 1991. Temperature is important because it controls evaporation which is periodically sufficient to allow areas of normally anoxic salt marsh sediment to dry and become oxidised; hence changing the speciation and mobility of some metals.

Table 1. Summary of maximum and minimum daily temperatures recorded at the Brisbane Airport for 1991. *Source* Bureau of Meteorology Brisbane.

	Jan	Feb.	Mar	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1991 Mean high	29.6	29.2	28.1	26.9	23.7	22.7	20.5	22.7	25.5	25.6	27.5	28.4
1949-91 Av.	29.1	28.9	28.2	26.5	23.5	21.2	20.6	21.7	23.8	25.7	27.3	28.8
1991 Mean low	21.9	21.4	18.8	15.8	15.5	11.2	7.7	9.2	11.1	15.9	18.6	19.4
1949-91 Av.	20.9	20.8	19.6	17.1	13.6	11.1	9.5	10.1	12.6	15.7	18.0	19.9
Mean Range	7.7	7.8	9.3	11.1	8.2	11.5	12.8	13.5	14.4	9.7	8.9	9.0
1949-91 Av.	8.2	8.1	8.6	9.4	9.9	10.1	11.1	11.6	11.2	10	9.3	8.9

Rainfall

Most of the rainfall in Moreton Bay is associated with Summer thunder storms. During the summer months (December to March), tropical cyclones periodically pass through or near the area producing high rainfall, strong winds and increased tidal heights (Coordinator General's Department, Queensland, 1974).

In comparison, the winter months are relatively dry (**Table** 2). Consequently, it would be expected that metal leaching and dispersion rates at

the Wynnum site will differ seasonally. **Table** (2) shows that 1991 was a sunnier year than average and Brisbane received only about half of its average yearly rainfall, with three months having a rainfall of 3 mm or less. As a consequence of the unusually low rainfall in 1991, it is likely that the rate of metal leaching at the Wynnum site may have been lower than normal during this study.

Table 2. Summary of rainfall and sunshine hours recorded at the Brisbane Airport for 1991. *Source* Bureau of Meteorology Brisbane.

	Jan	Feb.	Mar	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Rainfall	87.8	208.6	26.0	3.0	82.2	85.0	40.2	0	2.6	26.6	42.4	198
Average	167	168	144	94	85	76	67	45	33	97	98	125
Sunshine	255.1	230	257.8	286.7	183.6	234.8	273.5	293.5	301.1	256.5	249.9	299.6
Mean	7.3	8.2	8.3	9.6	5.9	7.8	8.8	9.5	10.0	8.3	8.3	9.7
Average	8.3	7.6	7.6	7.3	6.5	7.2	7.4	8.3	9.0	8.5	8.5	8.6

Hydrological Setting

Hydrological conditions at the Wynnum site influence both the distribution of mangroves and the dispersion of tip leachates (Saenger *et al.*, 1977; Dowling, 1986; Hutchings & Saenger, 1987). At the Wynnum site there are four distinct hydrological environments; the intertidal zone consisting of the tidal flats and most of the mangroves, the salt marsh and the zone of dead mangroves, the vadose zone landward of the salt marsh, and the phreatic zone which extends below the other three zones.

The intertidal zone is inundated daily by the tidal waters and because tidal height varies from a day to day the boundaries of this zone are variable. Although the intertidal zone is exposed at low tide, the sediments never fully dry out and experience few chemical changes. However, in the context of this study, tidal oscillations have two important effects. Firstly, because tidal waters are denser than most ground waters, tidal oscillations cause the water table to

rise and fall through chemically different zones in the sediment profile. Secondly, tidal water is chemically distinct from the ground water and the mixing of the two water types can lead to chemical reactions which do not occur in either original water type.

Tides in Moreton Bay are generally larger and fractionally delayed relative to the oceanic tides (Dowling, 1986). The Brisbane Bar is used as a reference point for tides in Moreton Bay, although there is evidence that some of the islands in the bay experience slightly larger tides than the bar (Coordinator General's Department, Queensland, 1974). **Table** (3) summarises the tidal data for the Brisbane Bar in 1991. Because the highest spring tides (**Table** 3) occur only a few times a year; the salt marsh surrounding the tip is seldom totally inundated by tidal waters .

Maximum water depths in the marsh zone varies from a few centimetres in the eastern portion to about 0.5 m just north of the tip (**Fig.** 2); during the dry season a large proportion of the salt marsh has no surface water. As a result of the shallowness of the marsh, seasonal variations in water level are marked and during the dry season, salinity increases substantially due to evaporation; during the rainy season the salinity of the water in the salt marsh drops as fresh water influx becomes dominant.

Water in the phreatic zone responds to tidal pressures daily as saltwater wedging forces the ground water to rise on the incoming tide. The saltwater wedge exposes the deeper sediments and the weathered basalt to cyclically varying chemical conditions and may influence metal dispersion and speciation. The extent of the tidally driven movement of the boundary between phreatic zone groundwaters and tidal waters will also vary seasonally in response to variations in the hydrostatic pressure of the groundwaters, groundwater flow volumes, and capillary suction through the vadose zone.

Water levels and water chemistry in the vadose zone (above the water table) are more variable than they are in the other three zones. Tidal

oscillations, rainfall and periods of surface dessication all have marked short term effect on the vadose zone and will influence chemistry of sediment-water interactions. The extent to which tidal cycles affect the water table position varies across the study area; at the tip face tidal changes in the water table level are minimal while closer to the coast the variation in lift over a tidal cycle is as much as 30 cm. Over much of the study area water loss from the vadose zone during the dry season, leads to an increase in the redox potential and a decrease in pH and in some sulphidic zones results in the temporary development of acid sulphate soils and enhanced leaching of metals.

Table 3 Summary of the high tide maximum heights for 1991 measured at the Brisbane Bar. *Source* Department of Harbours and Marine, Queensland 1991.

	Jan	Feb.	Mar	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Tot.
1.20-29	-	-	-	-	-	-	-	-	1	-	-	-	1
1.30-39	-	-	1	-	-	-	-	2	2	3	-	-	6
1.40-49	-	2	2	3	-	-	-	2	5	5	3	-	22
1.50-59	4	5	3	3	4	-	4	5	2	4	3	3	40
1.60-69	5	2	4	3	2	7	2	2	4	2	6	6	45
1.70-79	5	3	2	2	8	8	13	3	2	4	3	11	61
1.80-89	13	5	4	4	7	9	7	8	7	6	12	12	90
1.90-99	8	6	5	8	4	7	10	11	6	6	6	5	82
2.00-09	3	12	4	5	12	3	2	12	9	9	6	2	79
2.10-19	4	5	11	11	2	4	5	3	11	8	5	6	75
2.20-29	2	3	11	7	4	5	4	6	4	9	3	2	60
2.30-39	8	5	12	4	7	7	6	1	2	2	5	7	63
2.40-49	2	3	1	5	5	2	1	1	3	2	2	1	28
2.50-59	-	3	-	5	2	-	1	2	-	-	4	1	18
2.60-69	6	-	-	3	2	2	2	2	-	-	-	2	19
2.70-79	-	-	-	-	1	3	2	-	-	-	-	-	6

Geological Setting

The western part of Moreton Bay is composed of Quaternary shale, silt, clay and coral resting on a basement of Triassic-Jurassic sandstones and shales with some Tertiary volcanics and Paleozoic metamorphics (Heckel *et al.*, 1976; Heckel *et al.*, 1978; Stevens & Rogers, 1979).

Five of the 12 cores collected from the Wynnum site reached a massive low permeability green grey clay which contained abundant strongly weathered

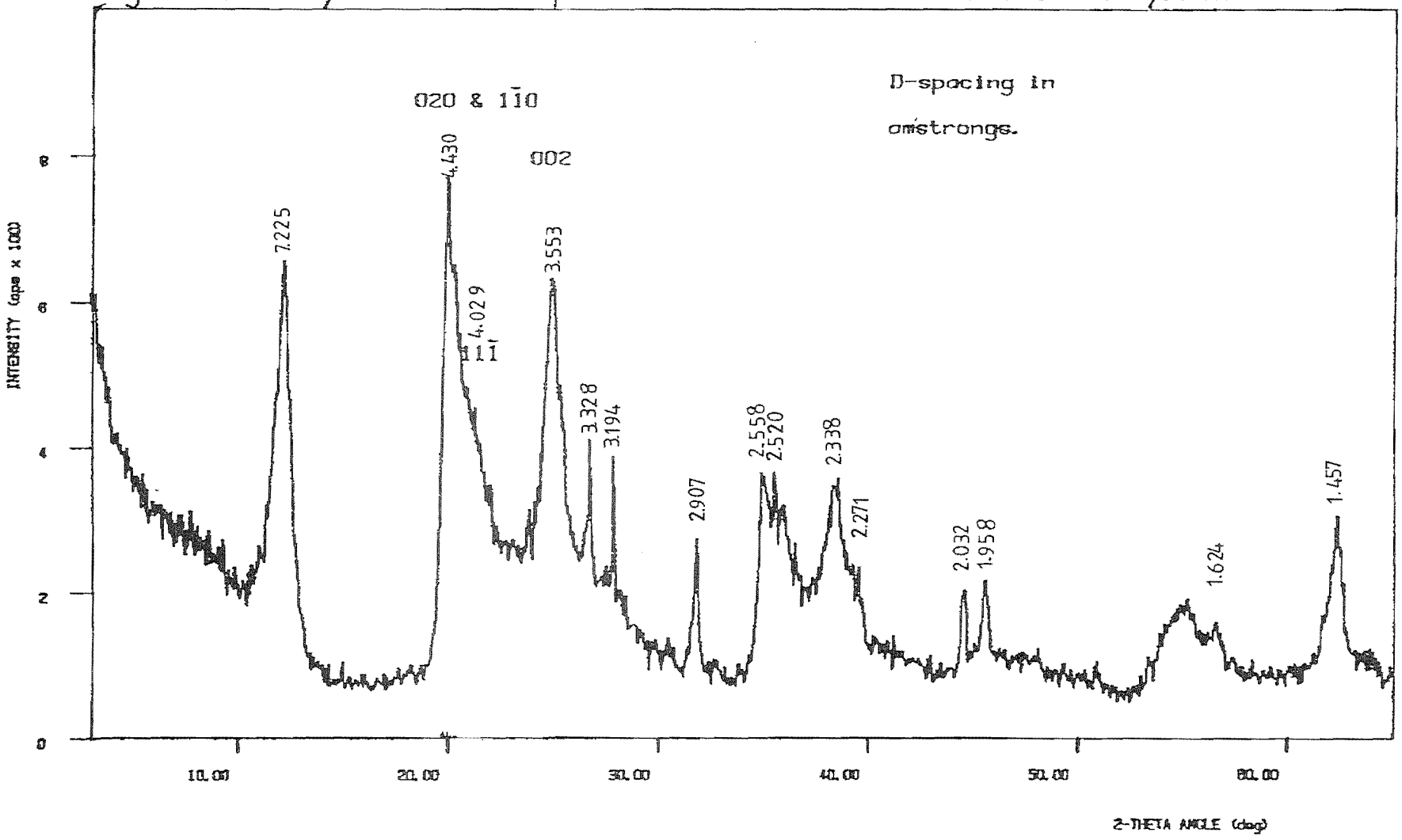
basalt clasts; these clasts suggests that the underlying basement at the Wynnum site is a weathered basalt. X-ray diffraction (XRD) data for the weathered basalt (**Fig. 3**) show that the basalt has been extensively altered to kaolinite and quartz; some plots reveal the presence of minor smectite in the weathered basalt (e.g. mcc12-07 and MCC 010-07; **Appendix 1**).

The kaolinite in the altered basalt shows very broad peaks and although resolution of the 4.439Å peak is too poor to allow determination of the Hinckley measure of disorder (Hinckley 1963), comparison with crystallinity plots from Murray and Lyons (1956) suggests that the mineral is very disordered. With the exception of illite which is produced from acidic parent materials (Barshard 1966), the weathering of either acid or basic parent material can produce a similar distribution of physils. The clay mineral assemblage in the Wynnum samples suggests a mean annual rainfall during weathering of 20 - 40 inches (500-1000 mm; Barshard, 1966; see also Sherman, 1952). However soil drainage is also important and a dominance of kaolinite in humid subtropical climates suggests moderate to good drainage (Weaver, 1989).

Overall it appears likely that the weathering of the basalt basement at Wynnum took place under similar climatic and hydrological conditions as exist today (i.e. a humid subtropical climate with rainfall of about 1200 mm).

The massive low permeability clay at a depth (1.5 - 2 m) in the Wynnum area is believed to have a major control on the movement of leachates from the tip. Leachate moving down through the sediments from the tip encounters the impervious clay and is forced to move laterally across it.

Figure 3. X-ray diffraction pattern of the weathered basalt at Wynnum.



Geomorphic Setting

At the Wynnum site there are five major geomorphic features; these are the intertidal mudflats, the mangrove belt, the salt marsh, the tip, and the fisherman's access road. The intertidal mudflats are extensive to the east of the mangrove fringe and extend up to 1 km from the seaward edge of the trees. The mudflats have a low gradient and are cut by a series of anastomosing tidal channels draining the surface in a southeasterly direction. The wide mudflats provide a protective barrier for the mangroves because the shallow water reduces wave action, which might otherwise undermine the mangrove root system (Dowling, 1986).

Mangroves at Wynnum form a narrow fringe parallel to the coast and because of their ability of to trap and accrete sediment there is a sharp drop of about 30 cm from the forest margin onto seaward mudflats. The gradient on the mangal sediment surface is shallow and rises gently to the west. As a result of the rise in elevation to the west there is a zonation in tree species and tree morphology. The zonation is a response to tidal inundation and results in sequential changes in dominant tree species and a progressive reduction in tree height for *Avicennia* from tall trees at the coast to a low shrub inland (Saenger *et al.*, 1977, Dowling, 1986; Hutchings & Saenger, 1987).

The low gradient and low relief within the mangrove forest results in local pooling of water, especially to the south of the fisherman's access. Drainage from within the forest in an easterly direction is via a number of short (c.a. 30 m) tidal channels, though some also drain in a more southerly direction. As with the small pools most of these channels are concentrated south of the access way. Tidal channels contain an abundance of unconsolidated fine sediment and at low tide often contain pools of surface water. As a result of the combination of low relief and the large number of drainage lines with pooled water, the forest south of the fisherman's access way is more waterlogged and consequently the sediment is more anoxic than the forest north of the access.

The fisherman's access way cuts the field area into two unequal portions and, compared to the mangrove forest floor, has a significant relief. The road surface consists of compacted, mostly schistose, rubble and the road while sloping gently to the east, also slopes from its northern edge to the south; the southern margin of the road merges smoothly with the southern mangrove forest floor. Whereas the northern edge of the road is raised (c.a. 15 cm) above the mangal sediments. The raised northern edge of the road acts as a dam and causes pooling of the surface water except where small drainage lines cut across the road. The road also acts as a conduit for runoff from the tip; run off tends to accumulate in the depression between the two tip cells before draining to the south into the mangroves.

The saltmarsh occupies the zone between the mangroves and the more elevated mainland. The marsh is nearly flat and has a low gradient that gently rises to the west. The eastern portion of the marsh is normally inundated, with the water occupying a shallow depression landward of the mangrove forest. This shallow depression allows the accumulation of about 40 cm of water that extends into the area of dead mangroves on the seaward side of the tip. Both the salt marsh and the area of dead mangroves are subject to intense evaporation and salinities twice that of seawater are common during the dry season.

The tip has an elevation of about 6m above that of the mean high water level (I. Woods, pers. comm.). The, nearly level, upper surface of the tip cell falls sharply to the saltmarsh to the northwest, the dead mangroves to the east and the fisherman's access way to the south. These steep slopes at the edge of the tip are heavily rilled by surface runoff and sediment transported down the rills extends several metres into the saltmarsh and dead mangroves to provide a thin veneer of oxidised sediment.

Sedimentation over the last 6000 yrs

The marginal marine sediments at Wynnum rest unconformably on a weathered basalt. The sediment cover is about 1.5 m thick in the southern part of the site, and thickens northward as a result of the gradual northerly dip on the unconformity.

Overlying the basalt is a shelly deposit with many shells embedded in the top of the weathered basalt . Carbon dated (by Beta Analytical, Florida) shell material from MCC 003 returned an age of 2660± 70 yrs.B.P.. This date gives a minimum age for the erosional surface on the weathered basalt. Another sample from 690 mm down core MCC 003 returned an age of 1440±70 yrs.B.P.. These two dates indicate average sedimentation rates for the area of 0.33 mm/yr. for the lower portion of the core and a rate of 0.48 mm/yr. for the upper part of the core. The greater sedimentation rate for the upper portion of the core reflects accelerated accretion following colonisation of the sediments by mangroves which trap and bind fine grained sediments. The dated shell species were either *Anadara trapezia* (Sydney Cockle) or *Batilleria australis* (mudwelk); both of these molluscs are found in estuarine environments; with sandy to muddy sediments (Shepard & Thomas, 1989).

Stratigraphic data from the 12 cores taken from the site are presented in a fence diagram (Figure 4) which shows the spatial distribution of sediments. The logged cores showed no primary sedimentary structures other than a few sharp contacts which probably correspond to erosional surfaces and/or periods of non-deposition; however subtle structures may be revealed by techniques such as x-ray radiography (e.g. Hamblin, 1962). All cores show a fining upwards trend in mean grainsize with a typical sequence grading upward from a coarse shelly lag deposit through a muddy medium to medium fine sand then a muddy fine sand and finally a silty or clayey mud.

Higher velocity tidal flows in channels have locally winnowed fine sediments to leave a coarse lag deposit; shells are abundant in these channel

deposits. Lateral migration of modern tidal channels has produced discontinuous units characterised by longitudinal crossbedding (e.g. see Reineck & Singh, 1975), but none of these units were intersected in the test cores.

Heckle *et al.* (1978) interpret the area as tidal flats associated with the development of the Brisbane River bird foot delta and **Figure** (4) shows a series of overlapping shelly deposits that are interpreted as lag deposits of distributary tidal channels; the fining upward sequence reflects infilling followed by tidal flat development and finally by muddy deposits associated with mangrove colonisation of the intertidal zone. Tidal flats (e.g. Jade Bay, Germany) show a similar tendency for muds occupy the zone closest to the shore while sand becomes progressively coarser off shore (Gadow, 1970 in Reineck & Singh, 1975).

The tidal mud flat and mangal forest sediments are heavily bioturbated by polychaetes, amphiopods, crustaceans, and gastropods (Frey *et al.*, 1989). Infauna population densities of up to 20,000 individuals per m^2 have been recorded for similar sites (Gerdes *et al.*, 1985) and it is likely that any primary sedimentary structures which may have been present were rapidly destroyed during bioturbation. All available evidence suggests that it is unlikely the environment for sediment accumulation at the Wynnum site has changed radically over the last 3,000 years.

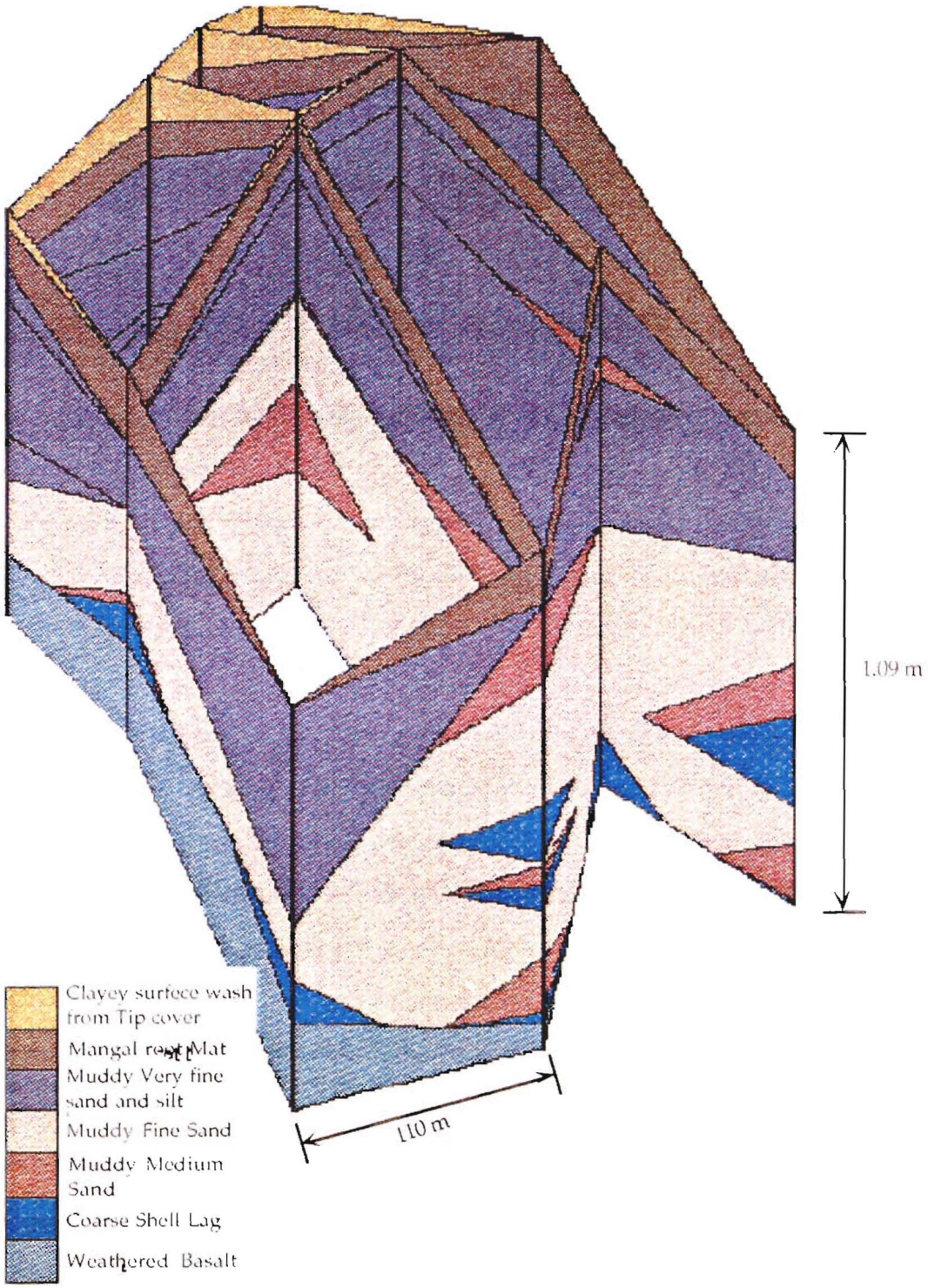


Figure 4. Fence diagram of the sediments at Wynnum generated from the core data. Diagram shows a series of overlapping channel lag deposits grading into channel fill and then to the mud flat sediments. The uppermost sediments are the finestgrained and reflect colonisation of the sediments by mangroves.

Recent changes in drainage

Analysis of aerial photos of the Wynnum area since 1964 reveals several changes in drainage patterns and the effect of these changes on vegetation cover. Some of the drainage and vegetation changes are associated with construction work that has been undertaken in the area since 1964. For example the blocking of drainage lines during construction works caused mangroves to die off in several areas when they were cut off from tidal influences. Although mangroves need not be directly inundated by the tide, most species do need to feel tidal action through their root systems (Hutchings & Saenger; 1987).

Figures 5, 6 and, 7 show the changes in drainage and vegetation patterns in the North Wynnum area recorded by 1964, 1978, and 1991 aerial photographs.

A comparison between the 1964 and 1978 photos (Figs 5 & 6) shows that construction of Port Drive and the railway to Fisherman's Island through the middle of the salt marsh has disrupted a westerly directed drainage resulting in the dying off of an area of mangroves to the east of the road (Figure 6). The northward extension of the refinery appears to have stressed the mangroves between Port Drive and the refinery but these trees are not yet dead. In contrast the tall trees on the seaward fringe of Whytte Island appear unaffected by construction work, and growth of the trees at the mouth of Crab Creek has been enhanced by nutrient supply from the sewage out fall in the creek.

The extension of Wynnum North Road to the coast, as a fisherman's access, has crossed a drainage line between the salt marsh and the coast and caused the drowning of a patch of mangroves north of the road. The actual date for the construction of the access way is unclear, but it is believed to have been around 1969 (N. Gibson, Roads and Works Department, Brisbane City Council, pers. comm.), and by 1978 the original drainage line has become indistinct.

By 1978 the southern cell of the tip complex was well developed and extended over an area of scrub land and scrubby mangroves so that only the tallest fringing trees remained (Figs 5 & 6).

A comparison of the 1978 and 1991 aerial photographs reveals further changes in the area. The construction of the marina and port facilities to the west of Port Drive led to the death of mangroves between Port Drive and the oil refinery (Figs 6 & 7). The marina facilities and the roadway servicing them, have probably isolated the mangroves from tidal movement. Parts of the southern end of the mangrove forest in this section have been infilled as part of an extension of the refinery.

Between 1978 and 1991 the large area of dead mangroves north of the fisherman's access way increased in size and the northern cell of the Wynnum tip was built over the western edge of the mangrove forest. It is unclear whether establishment of the tip helped increase the area of dead mangroves or if this was a natural continuation of the die off initiated by construction of the access way.

Since 1978 the mangrove island at the mouth of Crab Creek has increased in area so that is now joined to the mainland to create a sheltered embayment (Figure 6 & 7). The embayment is now being colonised by many mangrove seedlings which will presumably increase sediment accretion and push the coastline seaward in future.

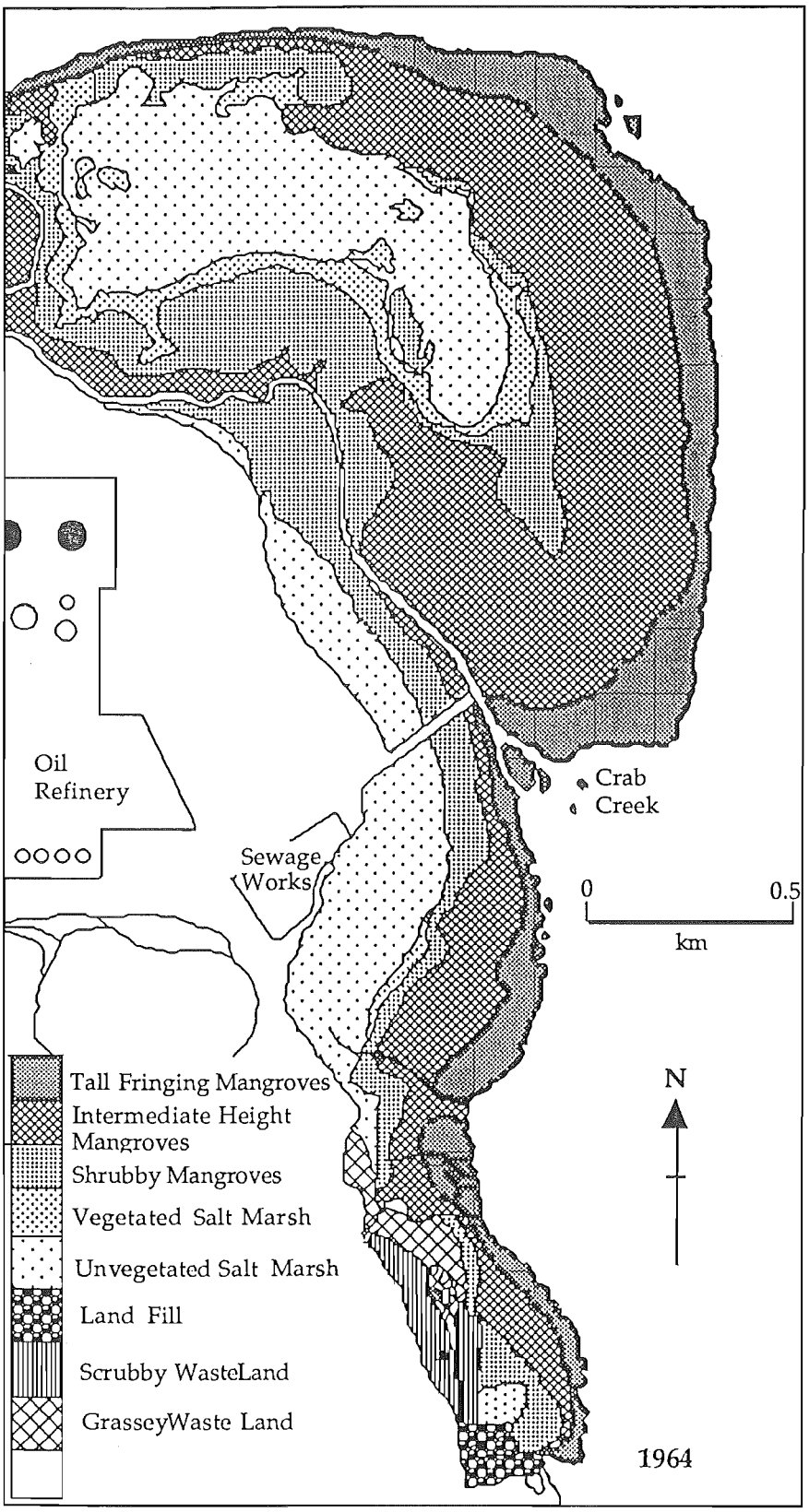


Figure 5 Map showing the land use and vegetation types of the north Wynnum and Whytte Island area for 1964. Map was constructed from the 1964 aerial photos of the area.

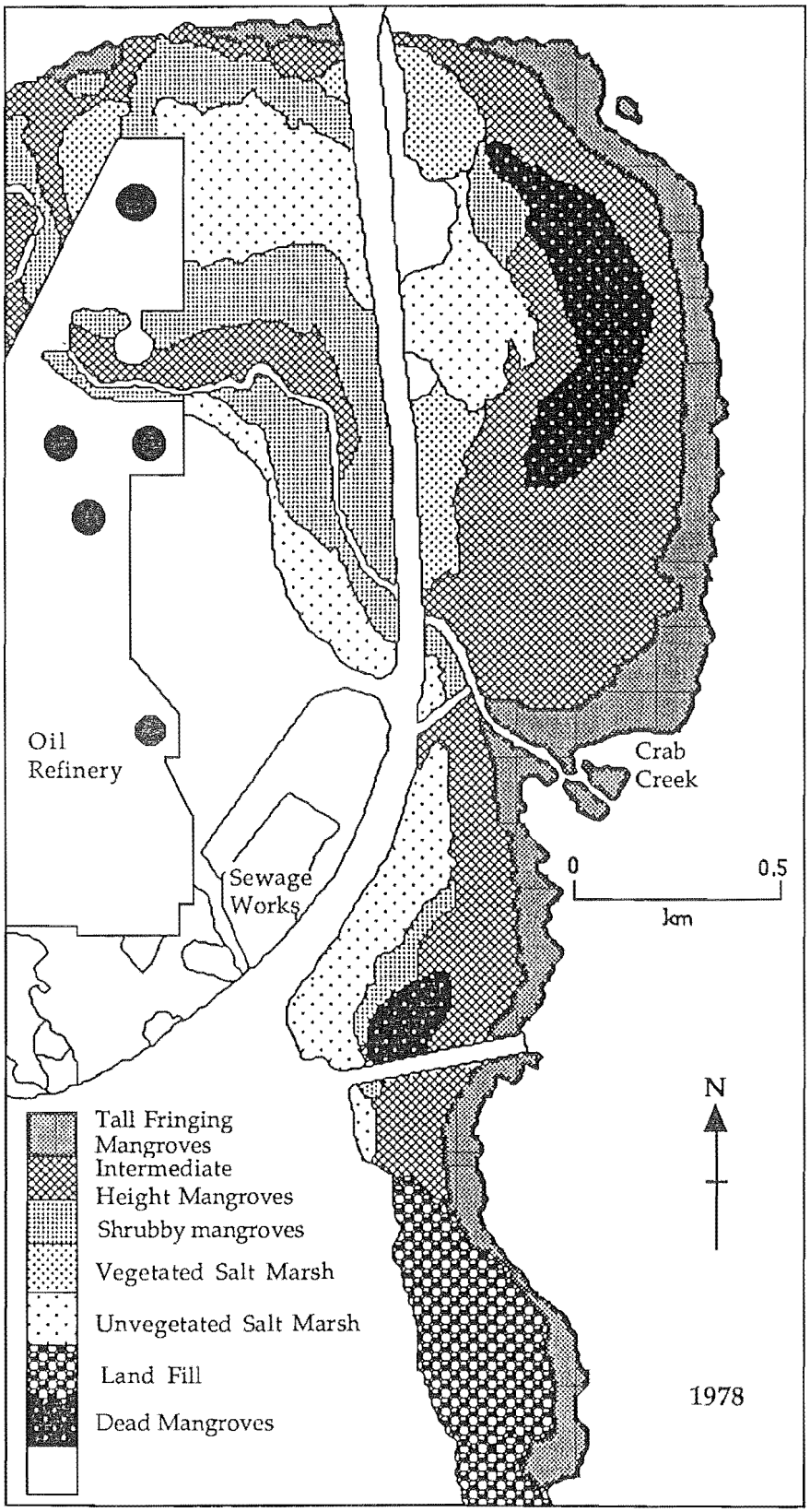


Figure 6 Map showing the land use and vegetation types of the north Wynnum and Whytte Island area for 1978. Map was constructed from the 1978 aerial photos of the area.

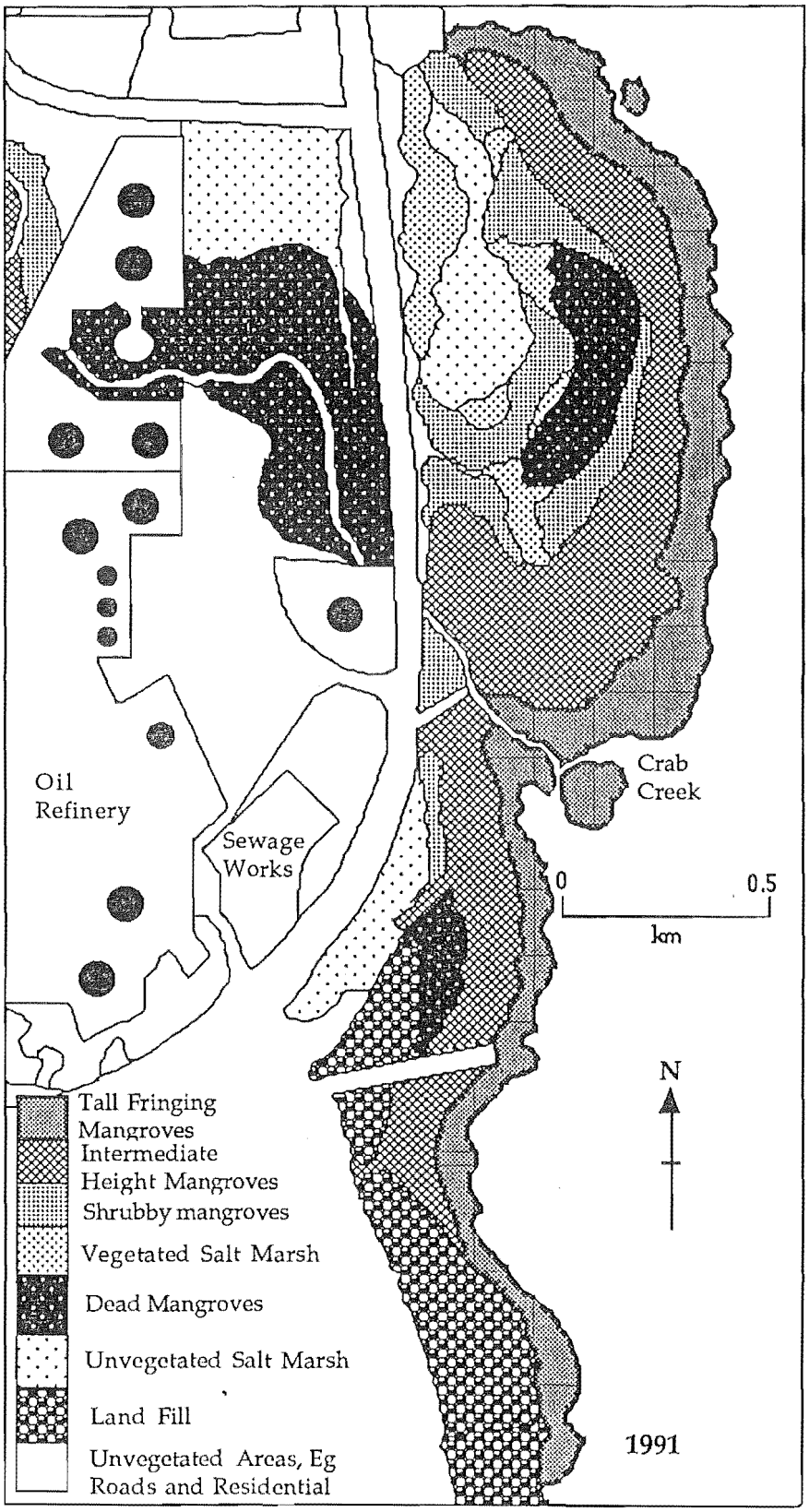


Figure 7 Map showing the land use and vegetation types of the north Wynnum and Whytte Island area for 1991. Map was constructed from the 1991 aerial photos of the area.

METHODOLOGY

Sediment Sampling

Core and grab samples were collected across the site from a parallel line sampling grid (Förstner, 1989; **Fig.** 8). An unequal sample spacing for core samples is employed because Saenger, McConchie and Clark (1991), show that contamination decreases away from the tip; hence sampling frequency is highest in the area of most rapid change in metal concentrations near the tip. The same parallel line grid with an equal spacing was used for surface grab samples.

Core samples.

Cores were extracted by driving a 3 m length of 50 mm P.V.C. into the sediment until about 500 mm of pipe remained above ground. Compaction factors are determined, by measuring the internal depth to the sediment (Di), the external depth to the sediment (De), and the total length of the pipe (L); and using of the given equation:

$$\text{Compaction factor (\%)} = \left(100 * \frac{(Di - De)}{(L - De)}\right)$$

compaction factors are summarises in **Table** (4).

Filling the above-ground pipe with seawater and sealing the end with a water filled plumbers dummy allows the core to be extracted with two opposing lifting handles (**Fig.** 9). The excess pipe is then cut off and the ends sealed with plastic bags.

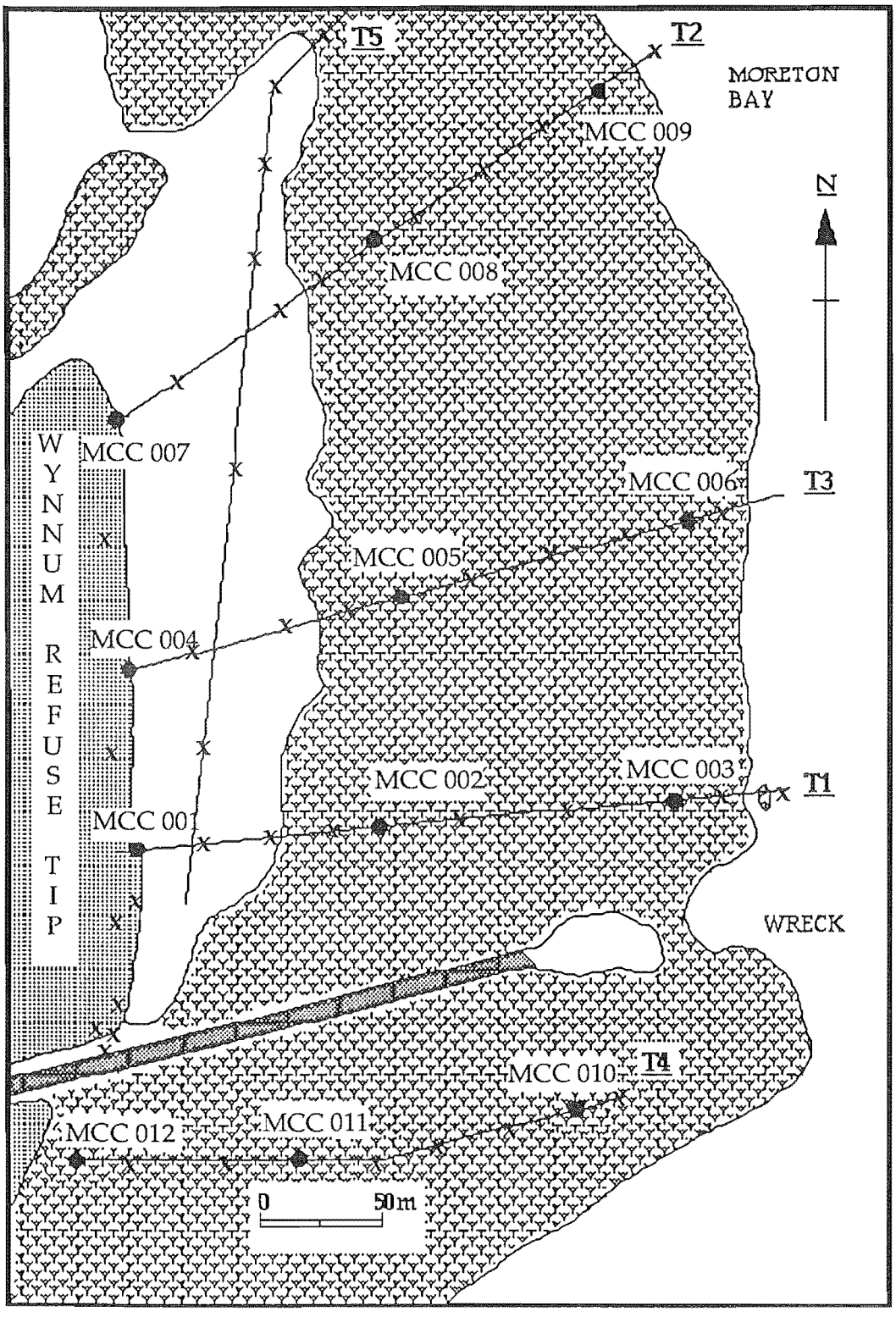


Figure 8 Map of the Wynnum Tip site showing the locations of cores and transects: **T1** (transect 1), **T2** (transect 2), **T3** (transect 3), **T4** (transect 4), and **T5** (transect 5; transect 5 continues to the coast off the northern edge of map). Filled circles denote core holes and Xs indicate where water or sediment samples were taken.

Table 4. Compaction factors for sample cores see **figure** 8 for location.

Core	MCC 001	MCC 002	MCC 003	MCC 004	MCC 005	MCC 006	MCC 007	MCC 008	MCC 009	MCC 010	MCC 011	MCC 012
%	39.0	56.5	51.9	53.6	54.6	49.6	59.1	47.4	54.6	48.0	47.3	25.5

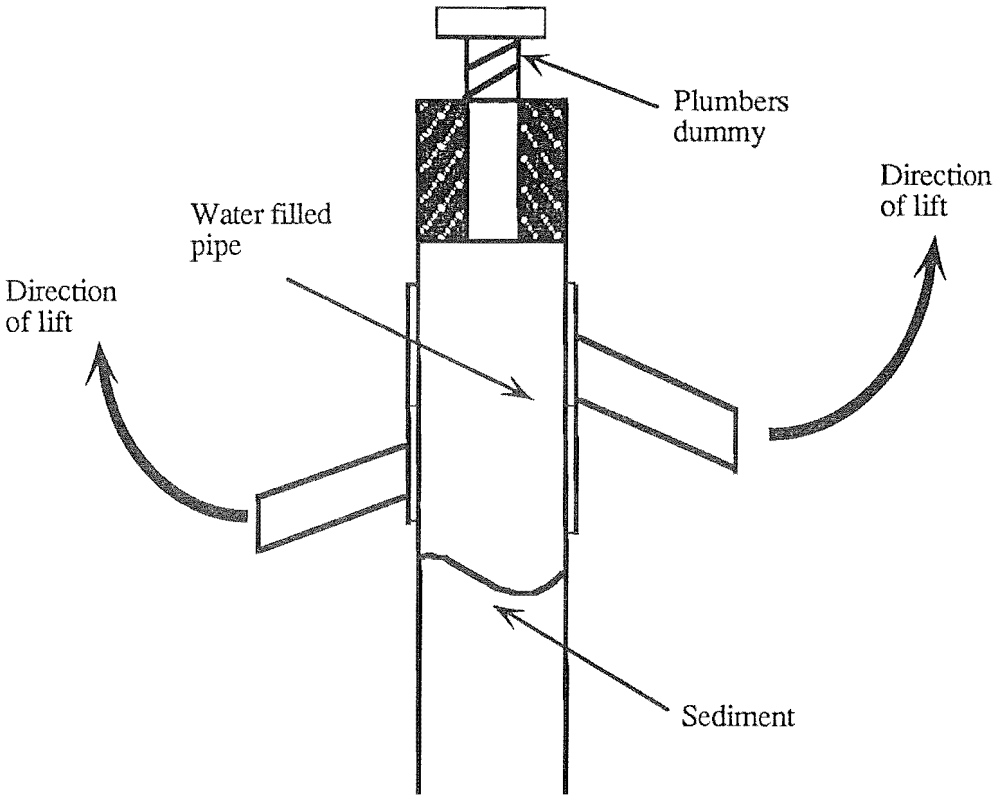


Figure 9 Cross sectional diagram of the core extraction technique using a plumber's dummy and a water filled PVC pipe; suction caused by the water extracts the sediment with the pipe during lifting.

Surface grab samples

A spade was used to take grab samples by shaving off a 5 - 10 cm slab from the side of holes dug into the sediment. Samples were collected from 2 depths at each sampling site: a surface sample spanning the depth from 0-5 cm and a sample spanning the range from 30-35 cm. As much air as possible was excluded from sample bags before sealing and labelling; air exclusion is necessary to avoid, or at least minimise oxidation of sulphidic material by

atmospheric oxygen.

Surface Water Samples

Water samples from natural pools of water on the sediment surface, or waters in the holes from which grab samples were taken, make up the bulk of surface waters collected from the Wynnum site. Other samples of storm water runoff from the tip and samples from the leachate drain are also included as surface water samples. Water collection was in 1 litre plastic bottles, which were washed in 1 M. nitric acid and rinsed three times with the water to be sampled. Air was excluded from the bottle before sealing and labelling the sample; air exclusion, to minimise oxidation reactions by atmospheric oxygen, required either complete filling of the bottles, or squeezing the bottle to reduce available air space to zero.

Groundwater Samples

Groundwater samples were taken from 6 piesometers set up in the core holes of transect 2 and 4 (Fig. 8). Piesometers constructed for this purpose consist of a 2 m length of 50 mm PVC pipe with numerous holes drilled the lower 1.5 m to allow groundwater inflow. The collection of groundwater followed the same procedure as for surface waters, but required sample extraction from the piesometer using a small hand pump.

Piesometers were monitored and sampled about every fortnight to detect changes in metal concentrations that might relate to events such as heavy rainfall or drought periods.

Surveying of the Field Area

Because pollutant movement in a setting such as the Wynnum site may be linked to leaching processes, both within the tip and within the mangal sediments, tidal flushing, and drainage patterns a detailed site relief survey is

likely to be particularly informative. In the salt marsh where there are areas of ponded water and areas which are relatively dry; there can be little doubt that chemical conditions in these subzones will differ. Similarly parts of the mangrove forest experience differing levels of tidal inundation: those closest to the coast experience diurnal variations whereas those parts nearest the marsh may only experience tidal inundation once a month. Hence Eh, pH and salinity conditions, which will influence metal distribution, are likely to vary as a function of small changes in site morphology and position.

Height survey

The height survey (levelling) of the Wynnum site was conducted using the reduced level method and a D.C.L. Tw-20A theodolite. This method uses the principle of height relationships and not the absolute height above sealevel. For the information that the survey was designed to provide (i.e., where are the high and the low spots in the field area, and in what direction might the metals move in response to relief gradients) this method is quite acceptable. As a starting point for the survey peg 1 was driven in about midway along the eastern edge of the northern tip cell and was assigned a height of zero metres. All other points in the survey are relative to peg 1 and consequently have no relationship to an absolute elevation.

Eh survey

The Eh survey was carried out simultaneously with the height survey. Eh readings were recorded at all possible height stations; Eh could not be measured along the fisherman's access way or on the tip cell itself.

Eh was measured in the area of dead mangroves with a Chemtronics RSP 1000 Eh probe, with modified head (Fig. 10); an Activon BJ513 combination Eh/pH probe connected to an Activon 205D combination digital pH/mV meter was used within the trees and on the mudflats. Two types of probe were used

because the RSP 1000 requires several mm of water to allow closure of the electrical circuit. At the time of surveying insufficient water among the trees prevented use of the probe there. Similarly the Activon probe can not be used in areas such as the dead mangrove area where water depth is over a few centimetres because the probe cannot be submerged. The Activon probe, thus could not be used in the area of dead mangroves. The advantage of the Activon system, for the work in the trees, is that only one instrument need be carried.

Probes were standardised against Zobells solution (1:1 mixture of 1/300 M potassium ferro- and ferri- cyanides), which has a standard potential of + 244 mV. The probes were inserted into the soft sediment and allowed to equilibrate for about one minute before taking the reading.

pH survey

The pH survey in the dead mangroves used an ICI 200 microcomputer pH meter and probe. An Activon BJ513 combination Eh/pH probe and Activon 205D combination digital pH/mV meter was used within the trees and on the mudflats. Two probes were again used because of the problems outlined for Eh data collection. Probe calibration was achieved by immersion in commercially available pH 4.0 and pH 7.0 buffers. Readings were taken after the probe had equilibrated with the sediment for about one minute.

Salinity survey

The salinity of the surface waters was measured using a Reichert-Jung 10419 temperature-compensating refractometer. A sample of water was collected with an eye-dropper and placed on the refractometer for measurement. This method of measuring salinity is likely to be more accurate than methods involving the conversion of conductivity to salinity because major-ion ratios may not be sufficiently constant to permit calibration using a single conductivity-salinity plot. Data collected from each survey was

processed using Mac Gridzo® 3.3.1 (e.g., see **Figs.** 15, 16, 17 & 18).

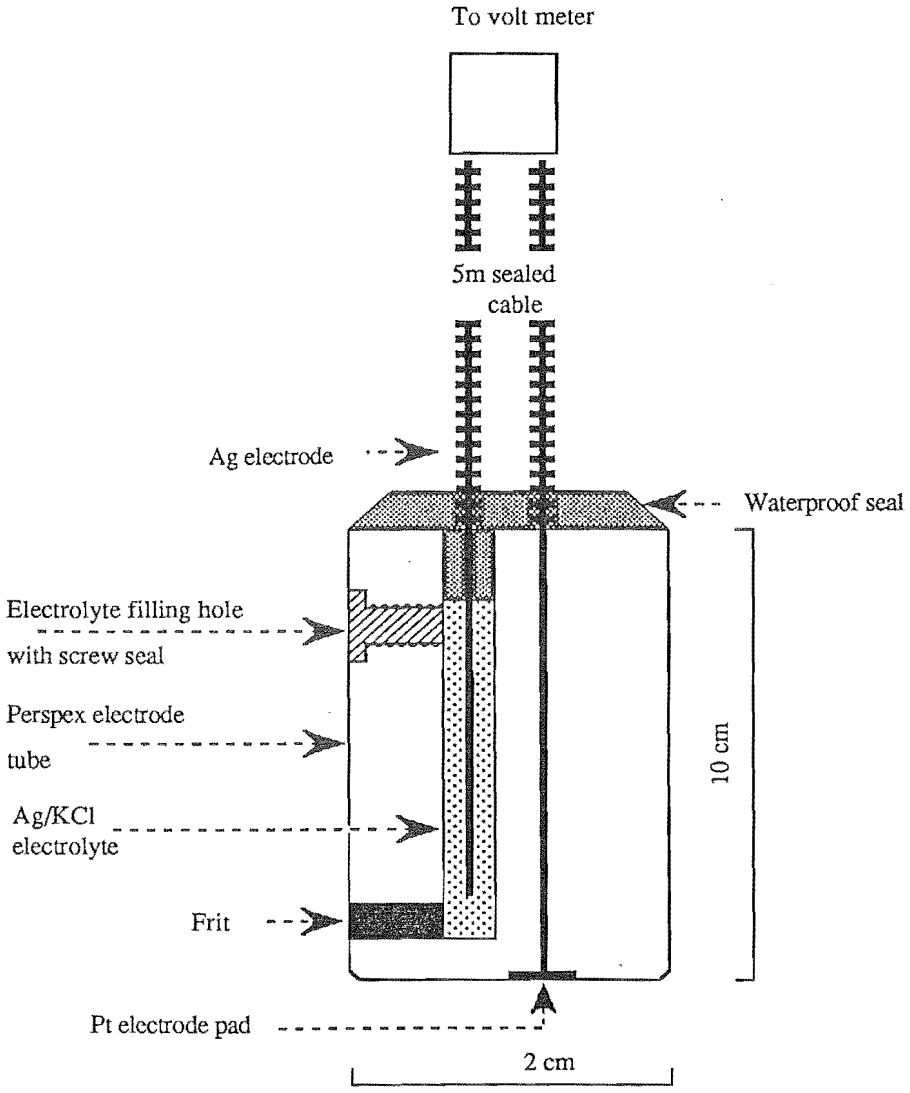


Figure 10 Schematic diagram of the modified head for the Chemtronics RSP 1000 as designed by D. McConchie (University of New England, Northern Rivers). Use of the modified head allows operation of the probe in very shallow (c.f. 5 mm) water.

Groundwater salinity

Changes in groundwater salinity and water table height during a tidal cycle were measured every two hours over a 13 hour tidal cycle to ascertain the influence of salt-wedging on the sediments. Groundwater salinity was measured using the refractometer and the water height relative to the sediment

surface was determined as:

$$\text{Height} = Di - De$$

where Di is the height of piesometer collar (top of the pipe above ground) to the water surface and De is the height of the collar to the sediment surface.

24 Hour Variation of Eh

Hansen *et al.* (1978) show that H_2S release from shallow lagoonal sediments is a diurnal event. Indeed the smell of H_2S in the field area was more noticeable in the early morning than later in the day. This diurnal event is regulated by the photosynthetic production of oxygen by algal mats during the day and subsequent oxygen depletion by respiration at night. The result of this alternation is that surface sediments are subjected to both oxic and anoxic conditions on a daily cycle.

The diurnal redox cycle has implications for the mobility and accumulation of metals in this type of environment. Metals entering the surface waters in the salt marsh during the day, when waters are well oxygenated and oxidising, may remain mobile for several hours, and may pass entirely through the zone. Metals entering the dead mangroves at night would be exposed to oxygen depleted sulphidic waters and consequently become immobilised as insoluble sulphides.

Because the influence of cyclic oxidation and reduction events on metal dispersion in contaminated sediments has not been documented in the literature, the sediments at Wynnum were monitored over a twenty-four hour period to observe the diurnal changes in the pH and Eh, and to determine the depth to which changes influence.

Method

Four sites were chosen near the Wynnum tip: site 1 , in the salt marsh; site 2, at the northern corner of the tip; site 3, south of the fisherman's access way; site 4, south of the fisherman's access way near the tidal limit (**Figure** 11). At two hourly intervals, the Eh of the sediment at both the surface and at all depths in the sediment of 1 cm, 2 cm, 3 cm, 4 cm, 5 cm, 10 cm, 20 cm, 30 cm, and 40 cm depths. The pH of the pore waters was also recorded. Because a new hole had to be dug every 2 hours, some variations in Eh/pH trends were expected. Because 4 separate teams were used for this work, it was also possible that minor variations in technique between groups could cause deflections from the smooth trends. To compensate for these problem the data was plotted on an Eh/pH diagram and by visually excluding those points that differed significantly to the other data. For example in core at a depth of 5 cm an Eh of +140 mV was recorded, which is significantly different to the other values of -250 to -350 mV.

The Eh probe was calibrated at site 2 on every sampling cycle both before and after measurement of Eh at site 2. Calibration of the probe was achieved by immersion in Zobells solution with a standard electrical potential of +244 mV against the Ag/AgCl reference.

Eh/pH Transitions

Because there are geomorphic and biogeochemically different subenvironments at the Wynnum site, transition zones between these environments were considered important sampling targets, which were likely to show rapid changes. The three major environments at the Wynnum site are: the area of dead mangroves/salt marsh; the mangrove forest; and the mudflats (**Fig** 11). Vertical and horizontal changes in Eh and pH over these two transition zones were measured.

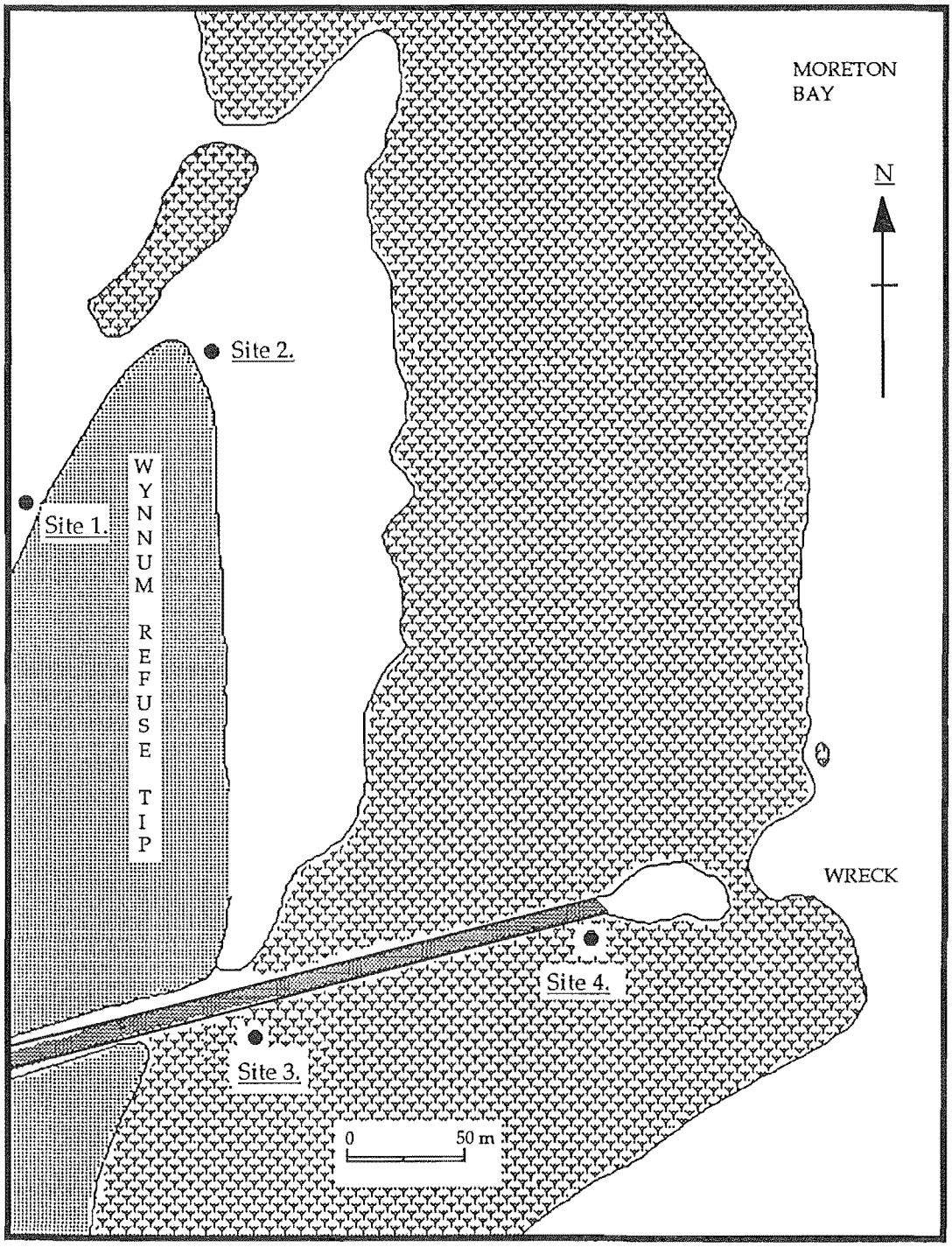


Figure 11 Map showing the site locations for the 24 hour Eh monitoring experiment. Site four is just above the mean high water mark. Site 2 is where redox probe was calibrated against Zobells solution for each run.

Method

Sediment Eh and pH at depths of 0, 5, 10, 20 and 30 cm were measured in series of holes dug across the transition zones. Eh was measured with the Chemtronics RSP 1000 with modified head (**Figure** 10) and pH measured with an ICI 200 microcomputer pH meter and probe.

Core Subsampling

Cores were first split by routing opposing sides of the PVC pipe to leave about 0.5 mm of tube wall. The 0.5 mm plastic wall remaining was cut with a sharp scalpel and a thin nylon cord was dragged along the core's length to split the sediment.

Subsamples were taken along the length of the core, with a closer sampling density in the upper part of the core. A 5 cm long sub-sample was taken at depths of 0, 10, 20, 30, 40, 50, 75, 100 cm, and if the core was long enough, at 125 cm. The samples were taken to leave a c. 5 mm zone of sediment next to the PVC to eliminate possible metal contamination come from the PVC. During sub-sampling, cores were logged for reconstruction of sedimentary environments (**Fig.** 4).

Grab Sample Subsampling

Grab samples were treated in similar way to core samples, in that sediment in contact with the plastic was not taken as part of the subsample. The sediment was split in two and the central portion of each half taken. Approximately a quarter of the total sample was taken as a subsample.

Sample Preparation

In dealing with sulphidic sediments, some specialised techniques are recommended to prevent sulphide oxidation by atmospheric oxygen. These include anaerobic glove-boxes, where the atmosphere has been replaced

(normally with nitrogen or argon) and sample manipulation is via a pair of air-tight rubber gloves in one wall (Rapin *et al.*, 1986). Other authors argue that delays between the time of sampling and extraction and the method and time of sample storage are important factors in preserving the chemical characteristics of the sediment, with sulphidic sediments being at one extreme (Thomson *et al.*, 1980). Thomson *et al.* (1980) and Rapin *et al.* (1986) go on to conclude that no storage or preparation procedure can preserve the initial characteristics of the sediment and that samples should be analysed as soon as possible after sampling.

Another technique involves the analysis of wet samples to avoid conversion of sulphidic material during drying in an oxygenated atmosphere. This technique requires a sample of known wet weight to be dried and a conversion factor used to transfer data from wet to dry weight values. However, because some of the reactions involving sulphide transformation result in mass changes, the calculated dry weight is not the true dry weight of the sample analysed.

Whether or not specialised techniques are employed, the most important consideration in comparative studies is to ensure that all samples are treated in exactly the same way. In this study samples from the Wynnum site were oven-dried at 65 °C for 3 days and then ground in a Labtechnics Pulveriser Mill (Model LM I/P) for 2 minutes. The crushed sediments were then sealed in air-tight containers for latter analysis. This procedure has the advantage of allowing the exact duplication of sample preparation conditions for a large number of samples

Grainsize Analysis

A number of authors (e.g., Tessier *et al.* , 1982; Förstner & Wittman, 1981; Luoma, 1990) have shown that the finer fractions of the sediment consistently have higher concentrations of trace metals than do the coarser (sand and

gravel) fractions. Clays play a dual role in metal accumulation, by exchanging metal cations (e.g., Ca, Mg, Na and K) from interlayer positions for contaminant metals, and by acting as a mechanical substrate onto which metals bound into organics and/or hydrous iron oxides can precipitate (Carrol, 1959; Grim, 1968; Teissier *et al.*, 1979; Jenne, 1977). Harbison (1986) noted that mangal sediments form an effective sink for heavy metals because of the abundance of fine grained sediment, which provides a large surface area for metal adsorption.

Many studies (e.g., Bouyocos, 1932; Olmstead, 1931; and Nelsen, 1983) have shown that the grainsize distribution not only depends on the duration of sample treatment, but also on the method employed; hence sample suites need to be treated in a consistent way.

Method

Dried and weighed sediment samples were soaked in 100 ml of 50 vol. hydrogen peroxide to destroy organic matter and to aid in the dispersion of clays. Because of the high salt content of many samples, each sample was washed with distilled water several times until the conductivity of the water was < 0.5 μS, or until deflocculation had occurred. Fifty ml of 0.6 gl^{-1} calgon solution (Lewis, 1984) was added to each sample and stubborn, samples were treated with an additional 2 ml of 40 % NaOH. Samples were then washed with deionised water and mechanically stirred with a hand-held homogeniser (food-mixer type) for 5 minutes.

Samples were wet sieved at -2, 0, 2, & 4ø on a Retsch shaker for 10 minutes at 70 % power. The sand fractions were then placed in pre-weighed plastic punnets and dried at 65°C for 24 hours before weighing. The silt and clay fractions (4, 6, 8, & 10ø) were analysed by standard pipette analysis (Lewis, 1984).

Total Extractions

Chemical extraction techniques used in this project provide data on the total metal concentration of a sediment excluding metals bound into silicate lattices. While "total extractions" may give a clear indication of whether metal concentrations are elevated, they do not assessment of interactions within the sediment or biological impacts (Thomson *et al.* 1980). "Total extractions" use concentrated mineral acid either singly (e.g., nitric acid) or combinations of these acids (e.g., $H_2SO_4/HNO_3/HCLO_4/HCl$ mixture, Förstner, 1989).

Because the organic content of the sediments is high, a nitric acid digest with an added oxidising agent such as hydrogen peroxide was considered to be most appropriate. About 1 g of sediment was transferred to a 100 ml beaker and allowed to react for a period of 15 minutes with 10 ml of 70% nitric. Samples were then heated and at 50°C the first of three 3 ml additions of 100 vol. hydrogen peroxide was made. After each addition of hydrogen peroxide the mixture was allowed to react completely before the addition of the next 3 ml. Once all the hydrogen peroxide was added samples were cooled, filtered through a 0.45 μm membrane filter and the filtrate was boiled down to < 10 ml and made up to 10 ml with deionised water.

Methods of metal analysis

A plethora of analytical techniques exist for the analysis of metal species. Samples from the Wynnum site were analysed by one of two methods: anodic stripping voltammetry (ASV), or atomic adsorption spectroscopy (AAS). Anodic stripping voltammetry was used to determine (Cu, Cd, Pb and Hg) because it is capable of simultaneous analysis of several metal species and because it provides better detection limits for many metals than does flame AAS (Potts, 1987; Chemtronics, 1986). Copper, cadmium and lead were analysed on the PDV 2000 using the standard technique outlined in the instruction manual (Chemtronics, 1986), while mercury was analysed using the

Chlor-Acetate buffer system (Jaya *et al.* 1985). Atomic adsorption was used for (Ni, Cr, Zn, Fe, & Sn) which do not require low detection limits because it is quick and accurate. The lower limit of detection depends on the method used (e.g., the detection limit for Cu by AAS is 25 μg/g, but by ASV it is 0.2 μg/g).

Sequential Extractions

Many researchers use sequential extractions (differential analysis) to distinguish trace metals in the various sedimentary sinks. As a result, many sequential extraction procedures have been proposed over the years (e.g., Tessier *et al.*, 1979; Rapin & Förstner, 1983; Engler *et al.*, 1977; Chao & Theobald, 1976; and Kersten & Förstner, 1986) (**Table** 5). Sequential analysis allows a clearer definition of the geochemical processes controlling metal concentrations and can provide predictive data on potential biological impacts of elevated metal concentrations (Thomson *et al.*, 1980).

While there are clear advantages in differential analysis over total analysis; stepwise chemical extractions have many problems (Kersten & Förstner, 1986; Rapin *et al..*, 1986; Campbell & Tessier, 1987; Förstner, 1989). The most significant of these problems are:

1) reactions are not selective and are not only influenced by the duration of the experiment but also by the solid-matter to extractant volume ratio (Campbell & Tessier, 1987, and Förstner, 1989). If the ratio of solid matter to extractant volume is too high, and there is an increase in buffering capacity, and the system will become overloaded. These effects may be reflected in changes in pH over time (Förstner, 1989).

2) Labile phases may be transformed during sample preparation. For example oxidation of phases may occur, especially in the case of samples from anoxic settings, or metals may be redistributed during extraction (Ajayi & Valoon, 1989). Campbell and Tessier (1987) argue

that over the 10 years prior to their paper, most environmental samples had been "mistreated" and that the geochemical and environmental relevance of the data from those samples was highly suspect.

In their study of extraction selectivity, Rapin and Förstner (1983) subjected pure carbonates (Cd, Ca, Mn, and Pb), amorphous iron/manganese oxides from deep sea nodules, two crystalline iron oxides (goethite and haematite), an amorphous iron sulphide and a crystalline lead sulphide (galena) to a number of extractants. Selectivity of their extraction methods was successful for

Table 5 Methods for the extraction of metals from major chemical phases in sediments. After Campbell *et al.*, (1987) with modification.

Adsorption and cation exchange	
Barium chloride - Trietanolamine (pH 8.1)	Jackson (1958)
Magnesium chloride	Gibbs (1977)
Ammonium acetate (pH 7)	Engler *et al.* (1977)
Barium chloride - Ammonium chloride	Gillman & Sumpter (1986)
Cation exchange resins	Duff *et al.* (1989)
Diethylenetriaminepentaacetic acid (DTPA) - Trietanolamine (pH 7)	Lindsay & Norvell (1978)
Carbonate phases	
CO2 - treatment of suspension	Patchineelam (1975)
Acidic cation exchange	Deuer *et al.* (1978)
NaOAc/HOAc - buffer (pH 5)	Tessier *et al.* (1979)
Reducible phases (approximate order of iron release)	
Acidified hydroxylamine (+ 0.01 M Nitric)	Chao (1972)
Ammonium oxalate buffer	Schwertmann (1964)
Hydroxylammine - acetic acid	Chester & Hughes (1967)
Dithionite - citric acid buffer	Holmgren (1967)
Organic fraction (including sulphides)	
hydrogen peroxide and ammonium acetate (pH 2.5)	Engler *et al.* (1977)
hydrogen peroxide and nitric acid	Gupta & Chen (1975)
Organic solvents	Cooper & Harris (1974)
0.1 M NaOH and sulphuric acid	Volkov & Formina (1974)
Na - hypochlorite	Gibbs (1977)
Na - pyrophosphate	Stover *et al.* (1976)
(DTPA) - NaOAc (pH 7)	Khalid *et al.* (1981)

carbonates (>85% extraction) and was acceptable for metals associated with the iron or manganese oxides, but the method was not selective for sulphides; the iron sulphide showed considerable progressive mobilisation in the early stages of the extraction sequence.

Testing selectivity

A similar experiment to that conducted by Rapin and Förstner (1983) was made to ascertain the selectivity of some chemical extractants. Ten naturally occurring and 5 synthetic sedimentary phases were treated with 15 (later extended to 16) extracting phases. Natural phases were pyrite, haematite, goethite, magnetite, siderite, chalcopyrite, galena, gypsum, marble, and a black calcite; the laboratory reagents consisted of red (mostly haematite) and brown (mostly goethite) iron oxides, lead carbonate, calcium carbonate and an iron monosulphide (troilite).

Method

Use of extracting phases was kept as simple as possible for ease of reproducibility and speed of analysis; complex extraction procedures which required multiple additions and rinsings of the samples were avoided. Procedures requiring heating were boiled for a quarter of an hour to avoid evaporation because extractant volumes were small. Cold extracts were shaken for 1 hour on a variable-speed rotary shaker, except for the dithionite extraction which was shaken for 12 hours as recommended by Holmgren (1967).

Five ml of the extractant was added 0.5000 $\pm$ 0.0005 g of solid phase in a 50 ml conical flask. After the reaction time the filtered samples were made up to 25 ml in a volumetric flask with deionised water. To avoid precipitation of insoluble iron oxides samples containing large quantities iron have to be acidified with nitric acid and evaporated before being made up to 25 ml with

deionised water.

Several methods were then tested on 1:1:1:1:1 mixtures of copper, lead, zinc, calcium carbonates, and iron sulphide. Because an extractant may mobilise an isolated phase, the behaviour of the extractant may be different for samples containing mixed mineralogy. The same ratio of solid-phase to extractant that was used for the single extractions was therefore used in this procedure.

Water was used as a baseline control for the extractions, and the concentrations the other extractants followed the procedures as outlined in the source reference (Table 5), except for the dithionite and the ascorbic acid/HCl extracts. The dithionite extractant was 90 gl^{-1} Citrate and 30 gl^{-1} dithionite, while the ascorbic acid/HCl extractant was 90 gl^{-1} ascorbic acid in 6% HCl.

Results and discussion

Results of the sequential extraction experiments are presented in Table (6) and results for the extractions for the 1:1:1:1:1 mixtures of metal carbonates and iron sulphide are presented in Table (7).

Water showed the lowest mobilisation of test minerals which was to be expected because solubility products for the various solid phases are low. Gillman Sumpter (Table 6) was the next poorest extractant, mobilising less than 1% of most solid phases, except the calcium carbonate and the marble. This extractant is commonly used to mobilise metals in the interlattice layers of clay minerals and metals loosely associated with organic matter (i.e., to measure the cation exchange capacity of the soil; Gillman & Sumpter, 1986). DTPA/TEA which is a stronger extractant than Gillman Sumpter showed moderate attack on the FeS and siderite phases. DTPA/TEA extractions are commonly used as an indicator of metals available to plants in soils (Lindsay & Norvell, 1978) because plants are able to extract metals from soils by the exudation of organic chelating agents and hydronium ions (Alloway, 1990). These chelating agents

have the capacity to transform solid phase forms of micronutrient cations into soluble metal complexes (Stevenson & Ardakani, 1972), it then follows that DTPA/TEA is capable of mobilising metals incorporated in sedimentary phases other than the exchangeable phase.

Hydroxylamine hydrochloride ($NH_2OH.HCl$) is used by many researchers (e.g., Chao, 1972; Chester & Hughes, 1967) as a reducing agent for the reduction of manganese and iron oxides. However in these experiments it showed only a weak ability to mobilise metals from any phase except for the zinc carbonate in the mixed sample.

Table 6. Data for the selectivity testing. Values are for the total percentage of the solid phase mobilised for the various extractants.

Sample	H_2O	DTPA/TEA		HAc/NaAc	Alk. peroxide		
		Gillman	$NH_2OH.HCL$		Peroxide		Dithionite
FeS (Iron Sulphide)	0.03	0.2	1.4	1.4	16	2.5	0.003	19
PYRITE	0.005	0.008	0.22	0.04	0.19	1.1	0.003	1.3
GOETHITE	0.003	0.006	0.05	0.02	0.03	0.04	0.4	0.3
HAEMATITE	0.003	0.005	0.1	0.01	0.003	0.004	0.003	0.2
MAGNETITE	-	0.01	0.09	0.08	0.09	0.02	0.004	0.3
SIDERITE	0.002	0.004	5	0.3	0.5	0.2	0.007	2
RED (Fe_yO_x)	-	0.005	0.09	0.04	0.2	0.04	0.002	0.04
BROWN (Fe_yO_x)	0.002	0.06	0.04	0.1	0.003	0.01	0.02	0.3
CHALCOPYRITE	-	0.008	0.02	0.1	0.1	4	0.002	0.35
CaCO3	0.03	2	0.6	2	13	0.6	0.0005	1
MARBLE	0.1	2	0.7	3	18	0.5	0.01	1
BLACK CALCITE	0.04	1	0.5	3	15	2	0.01	0.5
GYPSUM	0.03	0.03	0.005	0.008	0.01	0.09	0.001	0.007
PbCO3	0.01	0.05	0.2	2	57	0.5	0.6	0.3
GALENA	-	0.1	0.1	0.3	2	0.05	3	0.9

Sodium acetate/acetic acid, which has been used as an extractant for the carbonate phase (Tessier *et al.*, 1979), was found to mobilise as much metal from the iron monosulphide as the extractant was capable of mobilising from the carbonate phases (Table 6). In the carbonate/sulphide mixture selectivity of the acetic acid was considerably higher, and the carbonate phases were an order of magnitude more extractable than the sulphidic phase.

Table 6. Continued

Sample	Ascorbate/HCl		Hot 10%		Hot 30%	Nitric/ Peroxide		
		10% HCl		30% HCl		Nitric		Aquaregia
FeS (Iron Sulphide)	65	71	66	76	76	53	84	84
PYRITE	2.4	0.64	3	2.6	4.3	48	86	67
GOETHITE	11	0.9	49	18	69	0.4	4	60
HAEMATITE	11	0.9	15	20	58	1	7	63
MAGNETITE	67	14	49	67	81	2.2	18	73
SIDERITE	59	45	68	69	69	51	75	65
RED (Fe_yO_x)	5	0.9	25	36	43	2	3	33
BROWN (Fe_yO_x)	59	12	71	71	71	2	73	93
CHALCOPYRITE	0.06	0.1	0.8	0.5	2	3	29	18
CaCO3	50	57	64	72	65	59	48	54
MARBLE	37	58	54	55	67	86	44	60
BLACK CALCITE	49	82	81	84	79	82	83	87
GYPSUM	0.02	0.06	0.08	0.09	0.08	0.01	0.008	0.02
$PbCO_3$	16	7	6	40	33	96	92	19
GALENA	5	34	2	40	21	-	25	14

Table 7 The results of the selectivity of extracting phases from a 1:1:1:1:1 mixture of carbonates and iron monosulphide. Figures represent the percentage of each phase mobilised by the extractant.

Extractant	$ZnCo_3$	$CaCO_3$	$PbCO_3$	$CuCO_3$	FeS
Alkaline H_2O_2	0.6	0.7	0.7	0.1	0.04
NH_2OH	9.0	1.4	1.3	1.4	0.4
NaAc/HAc	49.2	14.4	7.5	8.0	1.5
Dithionite/Citrate	53.8	0.1	14.7	0.9	16.3
HCl/Ascorbate	100	21.9	24.0	79.0	33.8

Hydrogen peroxide is commonly a standard oxidant for the analysis of sulphides (e.g., Engler *et al.*, 1977; Gupta & Chen, 1975; Willett & Walker, 1982); however **Table** (6) reveals that the level of sulphide oxidation is low. Because the hydrogen peroxide is acid stabilised it reacts strongly with the carbonates evolving numerous gas bubbles indicative of CO_2 release. Precipitation reactions are postulated for the low extractability of galena and the iron sulphides; oxidation may be causing the precipitation of insoluble oxides and hydroxides.

Alkaline hydrogen peroxide was added to the list of extractants after the

carbonates were seen to suffer attack by standard hydrogen peroxide. By addition of sodium hydroxide to the hydrogen peroxide to a pH of 8.5 (carbonate/bicarbonate buffer limit), the attack on the carbonates by free H^+ is removed. Alkaline hydrogen peroxide acted solely as an oxidising agent, as shown upon addition to $PbCO_3$ and siderite. Lead carbonate reacted violently with alkaline hydrogen peroxide resulting in the transformation of the initially white solid to a dark brown solid. During this reaction, a large amount of heat and effervescent gas evolved. Because of the heat evolved in the reaction some of this effervescent gas is O_2 through the thermal decomposition of H_2O_2, where:

$$H_2O_2 + \Delta H \longrightarrow H_2O + 1/2\,O_2$$

The other component of the evolved gas is CO_2, which would be given off in a 2-electron oxidation reaction where:

$$Pb^{II}CO_3 + H_2O_2 \longrightarrow Pb^{IV}O_2 + CO_2 + H_2O$$

The presence of PbO_2 was confirmed by treating a large sample with the hydrogen peroxide, then analysing the product by x-ray diffraction; the resulting pattern showed PbO_2 peaks.

Siderite and the sulphidic substrates also produced vigorous reactions, with the originally pale siderite blackening. A 2 electron oxidation for the siderite is also proposed where:

$$2FeCO_3 + H_2O_2 \longrightarrow Fe_2O_3 + 2CO_2 + H_2O$$

or

$$3FeCO_3 + H_2O_2 \longrightarrow Fe_3O_4 + 3CO_2 + H_2O$$

The rapid rate of reaction of the alkaline hydrogen peroxide with the sulphidic and oxidisable carbonate substrates indicates that:

(1) the acid stabilisation of hydrogen peroxide causes a reduction in the rate of reaction probably due to the creation of $H_3O_2^+$ or similar species.

(2) acid stabilisation allows the undesirable dissolution of carbonates.

Alkaline-destabilised hydrogen peroxide, however, shows a marked decrease in

ability to extract sulphidic material (**Table** 6 & 7) due to uncontrollable reaction rates, which lead to thermal decomposition of the hydrogen peroxide.

Sodium dithionite/citric acid has been shown to mobilise iron oxides effectively (e.g., Holmgren, 1967; Förstner, 1989), but the data from **Table** (6) reveal that iron sulphide was attacked strongly by the dithionite and that iron oxides were relatively unaffected by it. The carbonate/sulphide mixture showed a moderate selectivity for the iron sulphide; zinc carbonate was strongly mobilised and the lead carbonate which was mobilised at a similar level to the sulphide. These findings are not consistent with the widespread use of dithionite as a reducing agent for ferric oxides and hydroxides possibly because the substrates used for this experiment were too crystalline for the extractant to mobilise effectively. The dithionite method may be best suited to removing amorphous iron oxides and hydroxides (e.g., Follett, 1965; Holmgren, 1967); which have a large surface area and weak interlattice bonds which are easily broken. In this study the apparent mobilisation of the sulphidic material may have been related to pre-oxidation of the sulphide by atmospheric oxygen prior to extraction. A X-ray powder-diffraction pattern of the sulphide shows that the mineral is not mono-mineralic and that magnetite, greigite and jarosite were present; it is possible that these other components provided the Fe extracted by the dithionite.

The stronger acids (e.g., HCl, HNO_3) showed little or no selectivity for any of the substrates present. While the HCl/Ascorbate and the other HCl treatments showed a selectivity for the more crystalline iron sulphides (pyrite and chalcopyrite), these extractants strongly mobilised either the FeS or the PbS phases. With the more oxidising extractants (e.g., nitric, nitric and hydrogen peroxide and aquaregia), all phases were mobilised without selectivity.

As showed that, Whereas it is easy to construct sequential extraction procedures for an oxic sediment, when sulphidic material is present, extraction methods currently used are not adequate (Rapin & Förstner, 1983). Even though

sulphidic materials used in this experiment were all strongly crystalline and therefore reasonably stable, the mobilisation of the sulphidic phase was not completely selective. Sulphidic material that commonly occurs in modern sediments includes hydrotroilite, which is metastable and is thus likely to be even more reactive; any change in the Eh/pH conditions, which all extraction methods exploit to some degree, will therefore rapidly alter and the original composition of the sediment.

There are further problems in differentiating between carbonates and sulphides, in that the Eh/pH boundaries for iron sulphides and siderite are similar (Figure 12). Again the use of redox conditions (by altering the pH or the availability of electrons) to mobilise one will invariably mobilise the other.

Conclusions

Due to the reactivity of the sulphidic materials present in anoxic sediments, there is no satisfactory way to determine the partitioning of metals in such samples. The best solution available is a sequential extraction but that reported data must be expressed as mobilising phase extractable (e.g., acetic acid extractable or dithionite extractable). While these extracting phases may loosely represent a particular sedimentary phase (e.g., NaAc/HAc for carbonates) the lability of other phases must be considered.

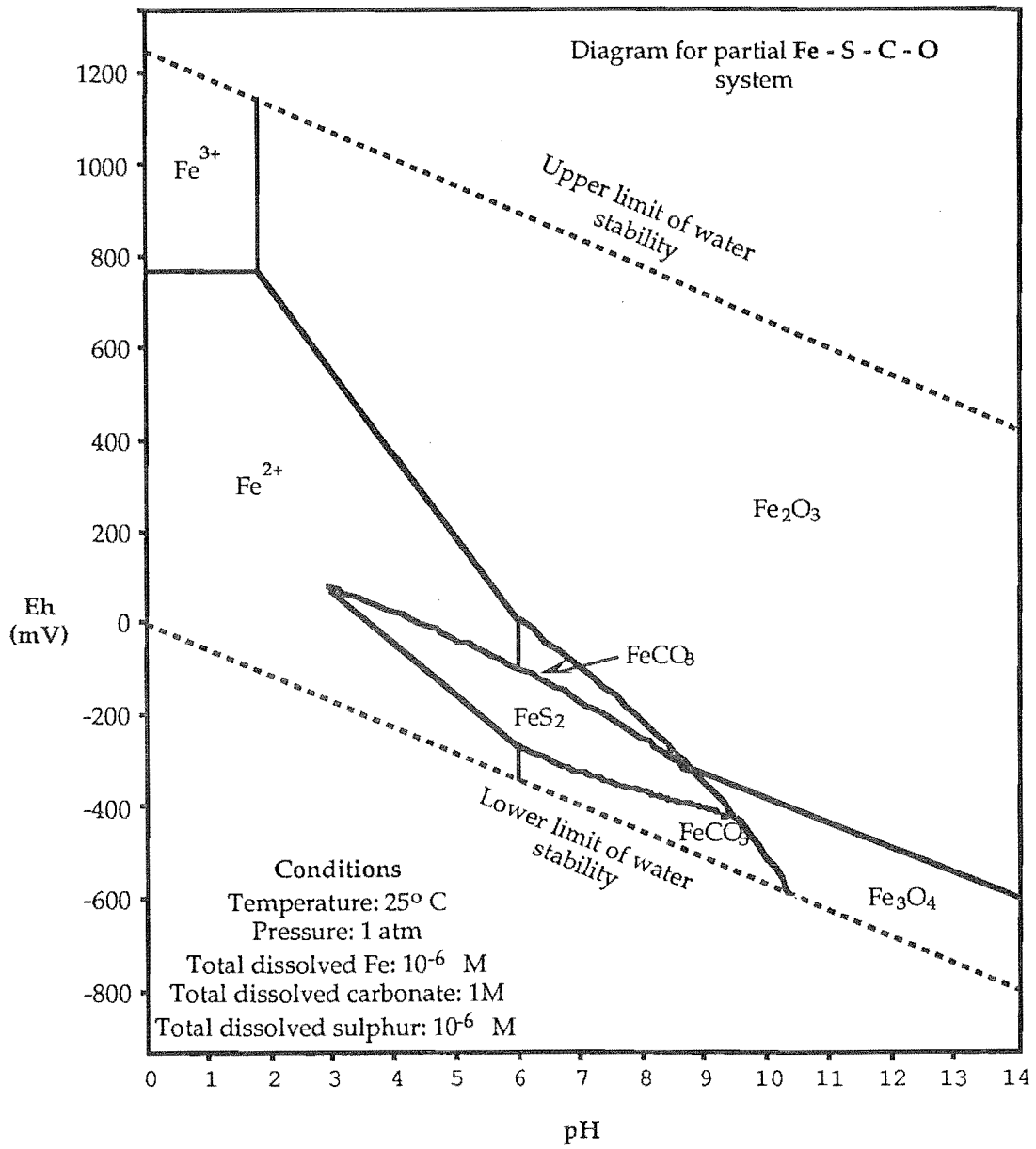


Figure 12 Eh/pH stability diagram for iron minerals.

Methods used

The methods chosen for the sequential analysis were: Gillman/Sumpter to represent the exchangeable phase; NaAc/HAc for the carbonate phase; Dithionite/citrate for the amorphous oxide and reactive sulphide phases, and aquaregia for organic and resistant sulphide material. Because more than one phase is mobilised to some degree by each of these extractants, data will be reported as phase extractable and not as sulphide-bound or carbonate-bound.

Approximately 2 g of crushed sample were placed in 100 ml beakers with 10 ml of 0.1 M $BaCl_2/NH_4Cl$ and shaken for 1 Hr. on a variable speed rotary shaker (Gillman & Sumpter, 1986). The sample was then filtered to 0.45 µm, the solid phase and filter returned to the beaker and the filtrates evaporated to near dryness and made up to 10 ml with ultrapure water.

The filter and sediment were then treated with 10 ml of 1 M NaAc/HAc (Tessier *et al.*, 1979), shaken on the rotary shaker for 1 hour, and filtered using the rinsed filter. Five ml of nitric acid was added to the filtrate before samples were boiled to near dryness and made up to 10 ml with ultrapure water.

The remaining sediment was then shaken for 12 hrs with 10 ml of 30 gl^{-1} sodium dithionite and 90 gl^{-1} citric acid. The sample was filtered and the filter removed and washed. 5 ml of 100 vol. hydrogen peroxide and 5 ml of nitric acid were added to the filtrate, boiled to near dryness and made up to 10 ml with ultrapure water. Removal of the cellulose acetate filter from the sediment at this point is to avoid filter destruction during aquaregia treatment .

Ten ml of aquaregia was added to the sediment and allowed to stand for 1 Hr. before being boiled for 15 minutes. Cooled solutions were filtered and the filtrate boiled to near dryness then made up to 10 ml with ultra pure water.

Plant Available Metals

One of the most widely-explored phases in soil-science studies is the adsorbed or exchangeable phase (Thomas, 1982; Lindsay & Norvell, 1978). These readily exchangeable metals are thought to represent metal that is weakly adsorbed on organics or occupying the interlattice positions of clay minerals (Grim, 1968; Jenne, 1977; Waller & Pickering, 1990). These metals are considered to be readily available for plant uptake (Brown, 1955). As a consequence of the nutrient-supply role that the exchangeable phase plays a number of extraction techniques for its investigation have developed (Table 5). It has been shown (Stevenson & Ardakani, 1972; Krom & Sholkovitz, 1978) that

the cation exchange capacity (CEC) of the soil/sediment (a measure of exchangeable metal) not only depend on mineralogy, but also on the organic matter type, and content.

Such non selectivity is consistent with the data from the sequential extraction data (Table 6 & 7), which indicates that the now commonly-accepted DTPA/TEA extraction mobilise portions of all physiochemical sedimentary phases, as required if the extractant is to reflect the plant available metal content of soils (Lindsay & Norvell, 1978).

Method

One g of crushed sediment was weighed into a 100 ml conical flask and shaken with 10 ml of 0.005 M DTPA, 0.01 M $CaCl_2$, and 0.1 M TEA (adjusted to a pH of 7.3) for 2 hours (Lindsay & Norvell, 1978). Samples were then filtered, boiled to near dryness, and 5 ml of concentrated nitric acid was added to destroy organics molecules that may complex with the metals and thus interfere with analysis by anodic stripping voltammetry. Samples were made up to 10 ml with ultra pure water.

Analysis of Organic Carbon

Organic matter contributes to the binding of metals in soil or sediment by both adsorption and chelation processes; Nye (1990) found that for *Rhizophora mangal*, the organic matter content of the sediment was the prime control on the metal load in the plant.

Organic matter undergoes several phases of oxidation, which may affect metal levels. The first is an initial loss of metals from decaying matter followed by a second phase of metal concentration as humification continues (Rice & Windom, 1982). Because many other authors also show that organic matter plays a major role in the mediation of heavy metals (Sohn & Rajski, 1990; Ephriam, *et al.* 1989b; Yeoman, *et al.* 1989; and Lion *et al.* 1982) it is likely that

this phase may play an important direct or indirect role in the mediation of heavy metals at the Wynnum site.

Method

In this study organic carbon is determined by the Walkley-Black method (Walkley & Black, 1934), which uses potassium dichromate and sulphuric acid as an oxidant and then back titrates the unused oxidant against ferrous sulphate to determine the concentration of organic carbon. For sulphidic sediments this method may give an overestimation of the organic content due to the oxidation of sulphide by the dichromate (Willett & Beech, 1987) but these errors are expected to be much less than natural sample variation over small distances at each site. Possible subsampling errors may also be significant because only about 0.06 g of sample is used in each analysis, but the speed of analysis is sufficiently high that multiple analyses of each sample can be conducted and averaged.

Analysis of Sulphate and Sulphide.

Sulphides in soils and sediments are likely to be an important sink for metals in mangrove sediments, which normally support a large population of sulphate reducing bacteria in a reducing organic-rich substrate (Wada & Seisuwan, 1986; Hutchings & Saenger, 1987; Förstner, 1989). The analysis of soil sulphate and sulphide is also important because these parameters define the acid-sulphate potential of the soil. Where a soil contains greater than 0.3% sulphur as sulphide, the soil is considered to be potentially acid-sulphate. Potentially acid-sulphate soils do not become acid-sulphate until the sulphidic material is oxidised as a result of a fall in the water table and soil drying. Sulphide oxidation and the associated production of sulphuric acid have significant affects on metal mobility in the soils (Willett & Walker, 1982; Dent, 1986; Olson, 1986; Wada & Seisuwan, 1986).

Method

Analysis of sulphate and sulphide involved the separate determination of water soluble sulphur (in the form of sulphate) and hydrogen peroxide oxidisable sulphur. The difference between these represents Sulphur present as sulphide.

For hydrogen peroxide-oxidisable sulphur, about 0.5 g of sediment is allowed to react for 48 hours with 10 ml of 50 vol. hydrogen peroxide. Samples are then filtered at 0.2 μm and diluted by 50:1 for HPLC (high pressured liquid chromatography) determination of sulphate. To determine water soluble sulphate about 0.5 g of sediment was shaken with 10 ml of ultrapure water, filtered to 0.2 μm and diluted by 5:1 for the HPLC determination of sulphate.

Samples were analysed by anion chromatography on a Dionex® AS4A column with Dionex® AG4A guard column and a post column Dionex® AMMS-II counter current anion suppressor (to reduce background). A 1.8 mM/1.7 mM $Na_2CO_3/NaHCO_3$ buffer solution pumped by a Kortec K350 pump at 2.0 ml/min was used as an eluent; suppression was achieved by 50 mM sulphuric acid delivered via a Dionex® pressure bottle, at 4 ml/min. Anionic species were detected by a Kortec® conductivity detector.

The above conditions gave a retention time of 6.7 minutes for the sulphate peak, with concentrations calculated by Nelson® peak-integration software using a calibration curve of 6 standard solutions.

Analysis of Waters

Direct analysis of water can be difficult because natural waters often contain very low levels of trace metals and for many elements a preconcentration step is necessary before analysis.

Preconcentration steps may be simple such as concentration by evaporation,

or more complex such as through the use of complexing agents and their extraction into organic solvents by a liquid-liquid extraction. For the analysis of trace metals by atomic adsorption, Clesceri *et al.* (1989) recommended the use of ammonium pyrolidine dithiocarbamate (APDC) as a complexing agent and methyl isobutyl ketone (MIBK) as the extracting solvent. There are many other complexing agents such as oxine, sodium diethyl dithiocarbamate (DETC), silver diethyl dithiocarbamate (SDDC), and dithiozone, which complex many metals, but each of these agents is specific only for a limited number of metals, (e.g. oxine does not extract Zn, Cd, Cr, or Hg whereas DETC does; Frieser & Morrison, 1959).

Although it is recommended that the Standard Methods (e.g., Clesceri *et al.*, 1989) be followed while conducting environmental chemical analyses, the APDC/MIBK extraction system is not, according to the authors, capable of extracting Hg. The inability to extract Hg is a problem because Hg is of environmental significance (Senaraten & Dissanayake, 1989) and it is a known contaminant from tip leachate (Garland & Mosher, 1975).

DETC has a similar structure to APDC, and also has the capability of complexing with all the metals to be analysed in this study (Frieser & Morrison, 1959) and was thus chosen as a replacement ligand for APDC. One advantage of the dithiocarbamate family is that they are able to complex metals that readily form insoluble sulphides in weakly-acidic conditions (Fritz & Schenk, 1979). DETC is also an extremely sensitive ligand for copper, with a very large (12 000) molar absorbtivity (BDH Chemicals, 1991).

Bauer *et al.* (1978) give an extraction method using DETC at a pH of 4.5 - 5.0 to extract copper into *n*-Butylacetate with EDTA (Ethylendiaminetetraacetic acid) as a masking agent to increase copper selectivity. By buffering the extraction system to a pH of 7.0, using a pthalate/hydroxide solution, and removing the masking agent, all metals requiring analysis in this study are completely extractable (Figure 13; Frieser & Morrison, 1959).

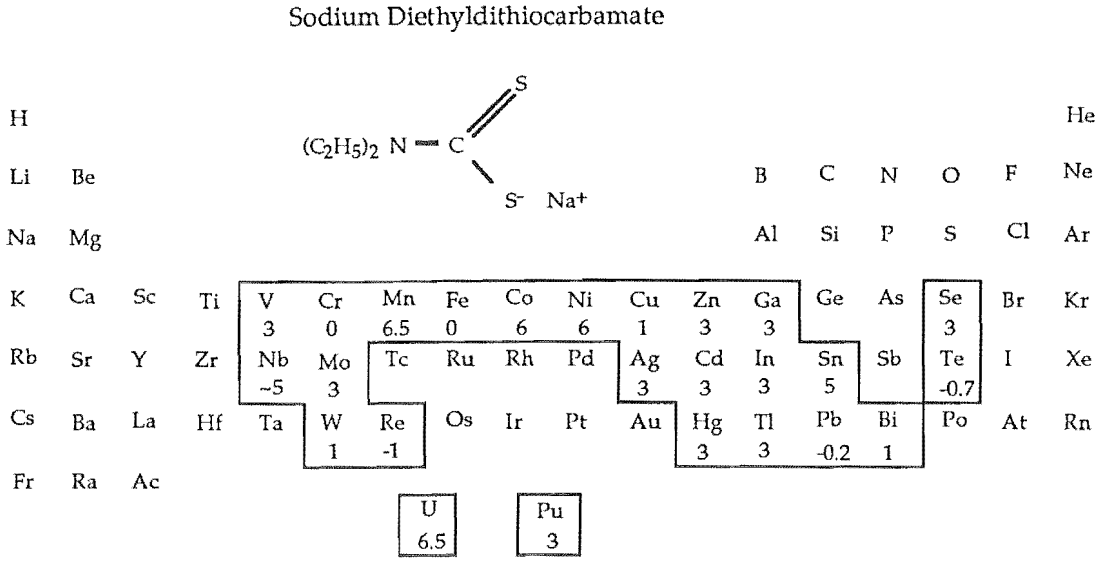


Figure 13 Elements extractable with sodium diethyldithiocarbamate. The number under each element symbol indicates the pH value at which the element can be completely extracted (modified after Freisser & Morrison, 1959).

Method

Two hundred and fifty ml of water was filtered at 0.45 µm and transferred to a separatory funnel. Sufficient pthalate/hydroxide buffer to bring the pH to 7.0 (usually 15 ml is required), and 3 ml of 0.243 M (5.485 g/100 ml) DETC and 25 ml of analytical grade *n*-Butylacetate were added to the separatory funnel. The separatory funnel was then shaken vigorously for 1 minute and allowed to stand until two distinct layers had formed. The lower aqueous layer was discarded and the acetate phase transferred to a 100 ml conical flask. The separatory funnel was washed with a further 25 ml of acetate, which was then added to the conical flask.

The acetate was evaporated to near-dryness in a fume cupboard and 10 ml of concentrated nitric acid and three, 3 ml aliquots of 30% (100 vol.) hydrogen peroxide was added to oxidise remaining organic compounds. The destruction of organic chelating agents is required for voltammetric analysis to ensure that

metals are electrochemically free and not locked up as stable chelates. Samples were then boiled to near dryness and made up to 10 ml with ultrapure water. This method gave a 25 fold increase in metal concentration for the PDV and a 5 fold increase in metal concentration for analysis by atomic adsorption.

RESULTS

Field Data

Data for the four surveys were contoured using Mac Gridzo® 3.3.1. These plots (Figs. 14, 15, 16, 17) are only models of the field area, and as such are only as good as the data collected. The major source of potential error is the selection of particular spots for data collection (only height data could be collected from the tip cell itself). Although all of the models show continuation of isolines under the tip, there is no way of knowing if the computer-generated isolines are correct and in view of this uncertainty isolines beneath the tip should be treated with caution. I the areas between the tip and the sea the contour plots are likely to be very reliable as a result of the high sampling frequency and trends revealed by the models will be unaffected any absolute errors.

Chemical data from the transition zones were graphed using Cricket Graph® 1.3.1 and data from the twenty-four hour monitoring are plotted on the iron mineral-stability diagram (Brookins, 1986).

Survey data

Data from the height survey (fig. 14) show that the topography is dominated by the tip cell, even though it was only surveyed to a relative height of 2.0 m. The other dominant topographic feature is the shelly mound at the end of the fisherman's access way.

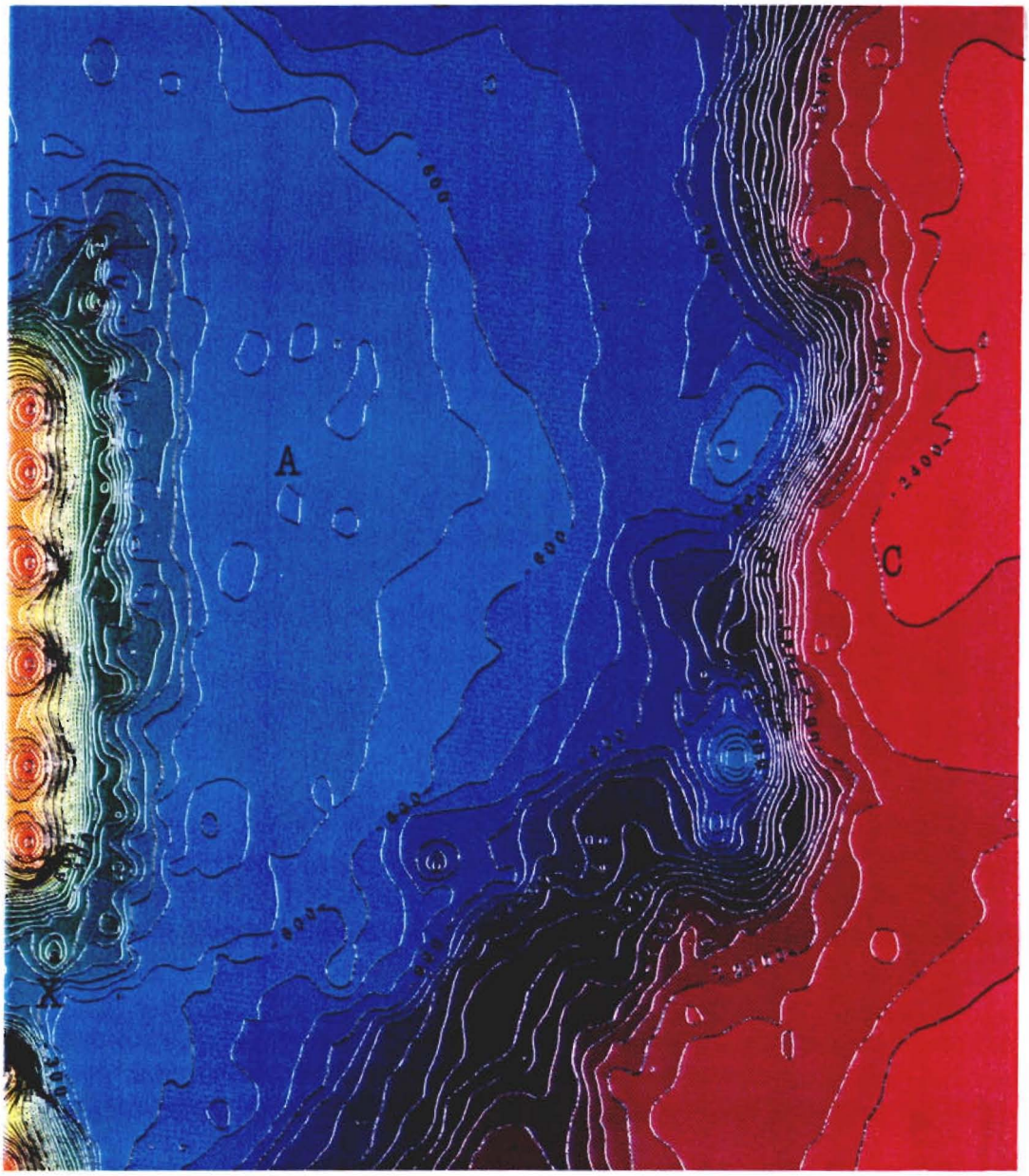


Figure 14 Contoured plot of the height survey data for the Wynnum area. Plot was generated from point data using Mac Gridzo® 3.3.1. Geomorphic overlay for **Figures** 14, 15, 16 and 17 in rear cover.

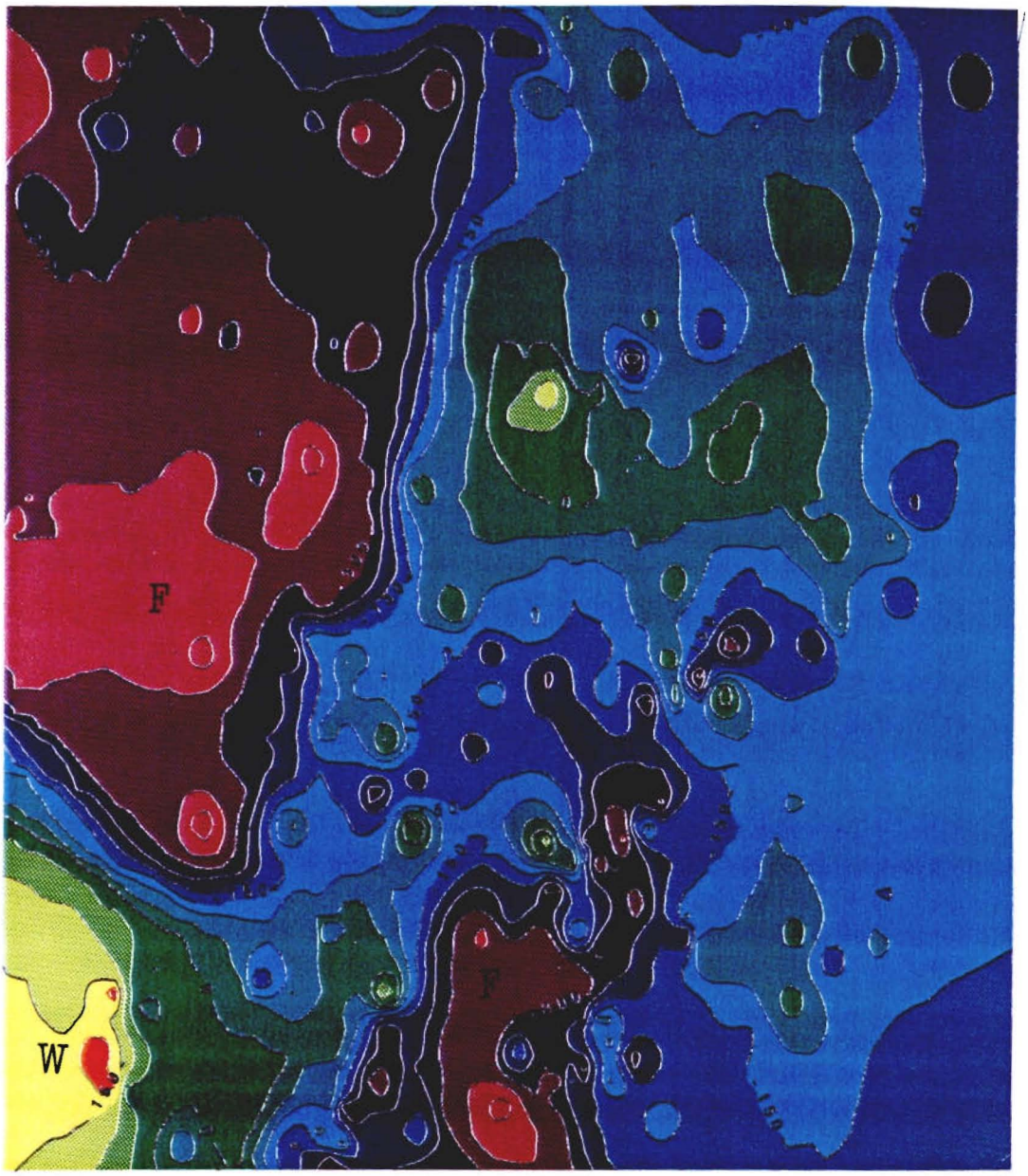


Figure 15 Contoured plot of the Eh survey data for the Wynnum area. Plot was generated from point data using Mac Gridzo® 3.3.1.

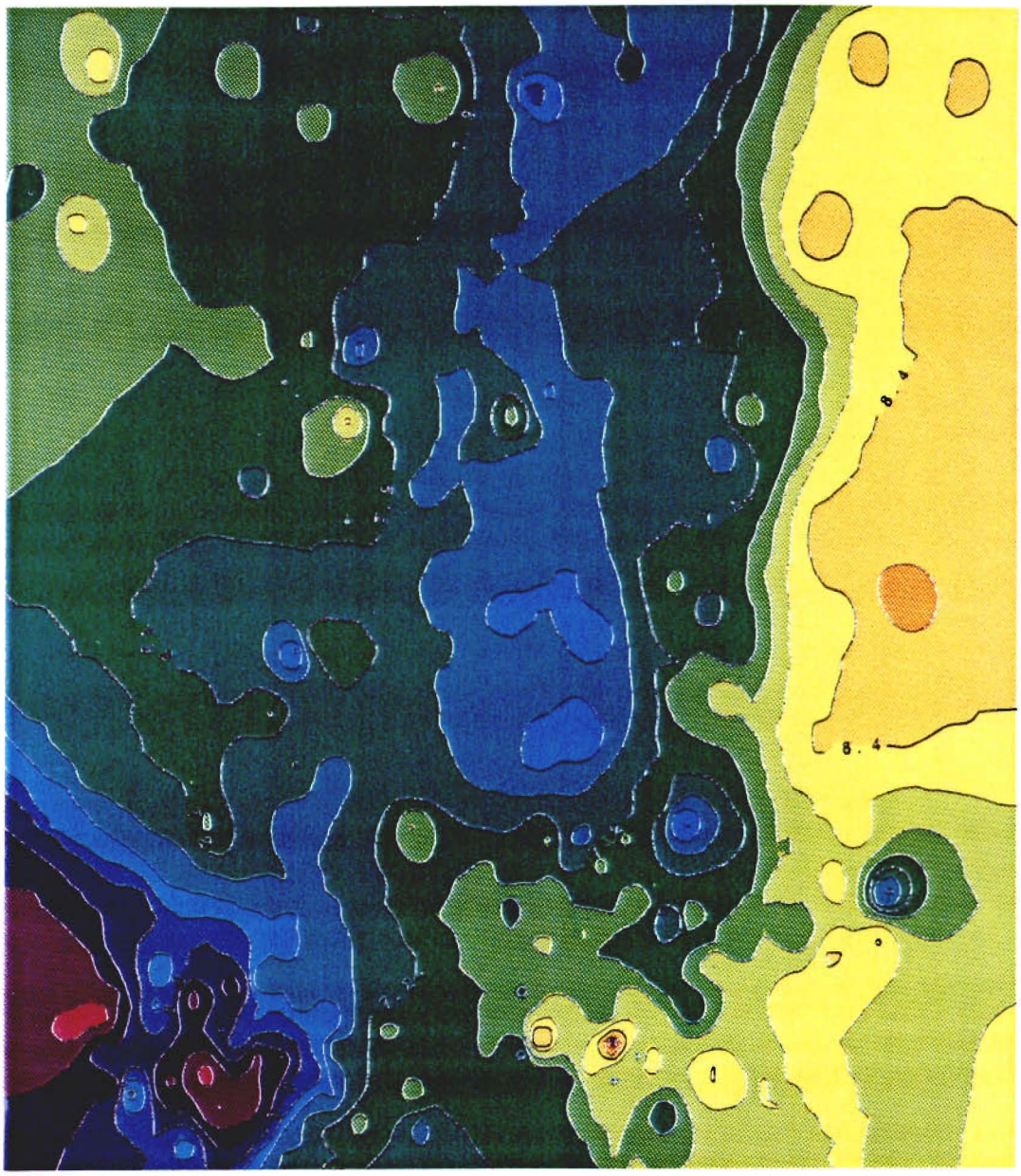


Figure 16 Contoured plot of the pH survey data for the Wynnum area. Plot was generated from point data using Mac Gridzo® 3.3.1.

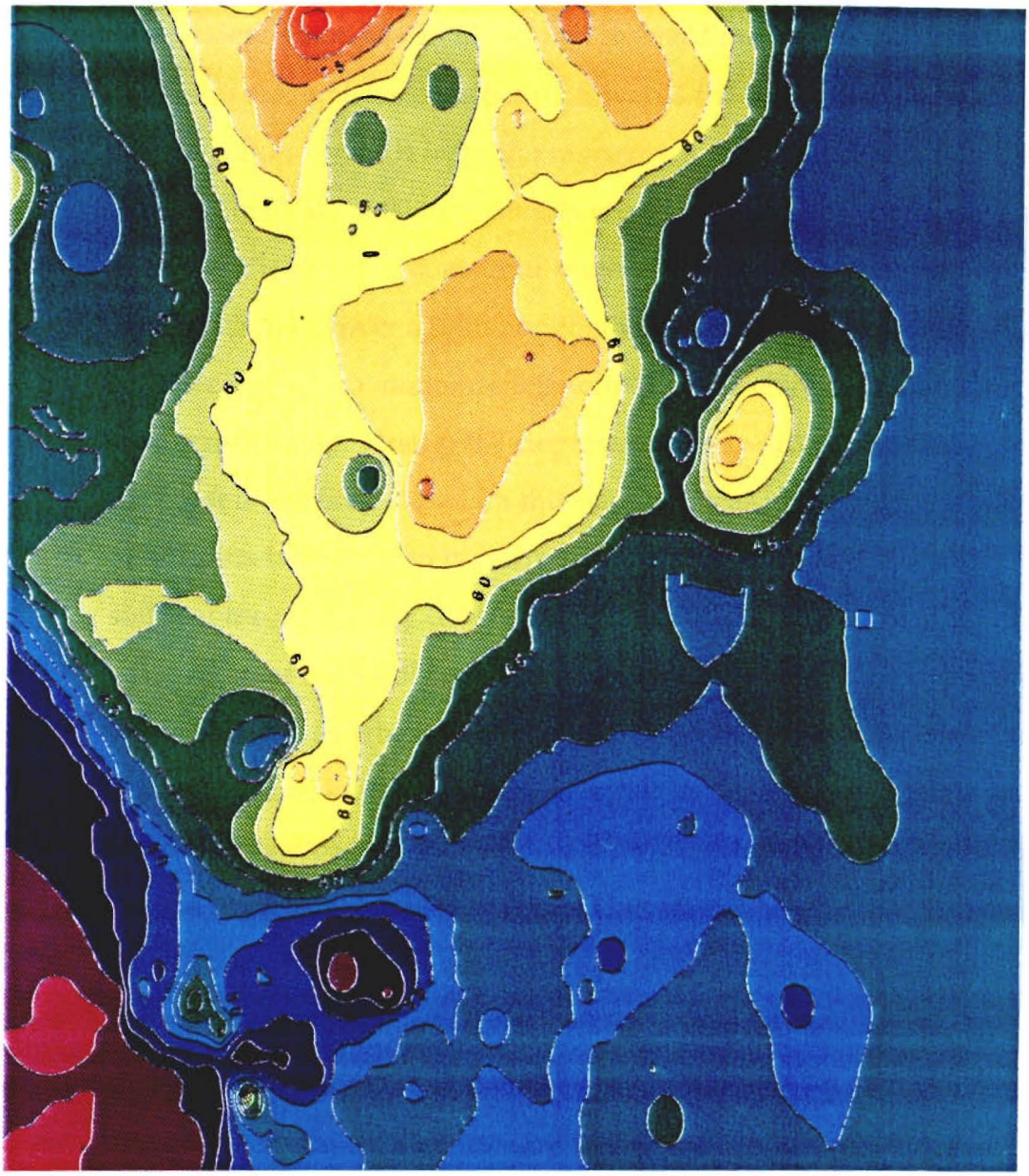


Figure 17 Contoured plot of the salinity survey data for the Wynnum area. Plot was generated from point data using Mac Gridzo® 3.3.1.

Two important topographic features are shown by the map (i.e. **fig** 14): 1) the water-filled depression that contains the dead mangroves (A), this rather patchy depression has an ill-defined seaward margin and; 2) The mangrove-covered area, which slopes gently towards the coast, then steepens through the transition zone (B) from the mangroves to the mud-flats (C). (Note: the contour intervals of 50 mm, reveals changes in slope are not always obvious in the field). The 50 mm contour interval also makes the transition zone (B), which falls 1.5 m over a 50 m horizontal distance, appears cliff-like.

There are two main deficiencies in the computer contours of the topographic map. Firstly, the depression landward of the shelly mound at the coast is not fully closed on the map, whereas in the field it is water-filled and drains through a very narrow exit to the southeast. Secondly the area south of the access way (D) is depicted as a steady slope from the road to the coast whereas it actually contains large numbers of shallow depressions and tidal channels, in which tidal waters remain at low tide. The symbol (X) in **figure** (14) marks the position of a leachate seep (see **Metals in waters** *Surface waters* page 101).

The Eh data, contoured in **figure** (15), reveals several distinct zones in the area. Areas of standing water (F) are sharply contrasted with those areas that are well drained, because where water is allowed to stagnate, the Eh falls sharply. These two stagnant-water areas, connected by a thin ribbon of low and discontinuous Eh values, are interpreted to be a drainage line for the dead mangroves which the height survey was not able to detect. This zone of lowered Eh runs parallel to the fisherman's access way, then merges with the pooled water at its eastern end. This zone is the most likely position for the drainage channel for the dead mangroves because the original drainage ran in a southerly direction before the construction of the road.

In well drained areas (W), such as the mangrove flats to the south of the road and just east of the southern tip cell, the Eh rises to + 250 mV and the

sediment is well oxidised. The only other major zone that has a positive Eh are the mangrove flats east (F) of the dead mangroves; the higher Eh in these areas is probably related to a low frequency of tidal flooding.

The Eh map (Fig. 15) defines the shallow depression that contains the dead mangroves better than the height survey because the Eh is a direct reflection of soil anerobis hence the water-logging of the sediment.

The pH contour map (Fig. 16) shows reverse patterns to those of Eh (i.e., where Eh is high the pH is low). The lowest pH (c. 4.5) corresponds to the highest Eh (+ 250 mV) and occurs south of the fisherman's access way and east of the southern tip cell. The pH of water in the area of dead mangroves ranges between 7.2 to 8.1, depending slightly on the position of the reading, most of these readings were taken in early morning, which may account for differences between the survey readings and other pH readings taken from this area in the afternoon (c.f. the plot of 24 Hr. Eh/pH variation in figure 27 for this site).

Sediment pH falls in the mangrove forest as Eh rises, but rises again as the influence of tidal water increases toward the coast. The fall in pH within the trees probably linked to the rise in Eh, which reflects some surficial oxidation of sulphides and resulting production of minor quantities of sulphuric acid. Another possible explanation for the fall in pH may be the absence of the carbonate/bicarbonate buffer (pH 8.2) that is present in seawater; without the carbonate buffer, soil falls back to near or slightly below neutral value.

To the south of the fisherman's access, where there is an abundance of tidal channels and pooled water, the pH of the sediment is high; a pH of 9.5 was recorded in one pool of water; the pH of the pooled water is more commonly near that of seawater, at about pH 8.2. The elevated pH in some pools is thought to reflect local bacterial ammonia production. The high pH anomalies are superimposed on the regional trend for sediment that is in

regular contact with seawater expected to have a pH close to that of the sea water, while areas not in contact with seawater are expected to show a fall in soil pH to near or slightly below neutral.

The salinity map (**Fig.** 17) depicts areas that are influenced by fresh water run-off, by regular tidal inundation, and by tidal inundation followed by evaporation. Sediments regularly inundated by tidal waters have a soil salinity close to that of the tidal water, whereas evaporation produces local areas with higher salinities and freshwater runoff leads to areas with a reduced salinity.

The area of mangroves affected by sulphide oxidation (high Eh, low pH) is also affected by freshwater runoff, with salinity for the area falling to < 15 ppk (parts per thousand). The salinity together with the data for Eh and pH, indicates that this site is well drained and experiences little or no tidal inundation. In contrast, the area of dead mangroves shows an increased salinity, commonly 1.5 times that of seawater, indicating infrequent tidal inundation and substantial evaporation. Because there was significant rainfall several days prior to collection of the survey data, it is likely that salinities in the area of dead mangroves are normally higher than the values recorded here..The highest salinities recorded in the area (90 ppk) are in the northern part of the dead mangroves where the last surface water remains after prolonged evaporation. Another area of elevated salinity (twice that of seawater) occurs mid-way up the seaward edge of the mangroves between the end of the road and the northern extent of the map where a topographic high (**Fig.** 14) prevents regular tidal flushing.

To the south of the road, soil salinity shows that the area is subjected to regular tidal flushing and that there is little or no evaporation of pooled water. This interpretation is consistent with the other survey data for this area, which indicate that the area is water-logged and anoxic, with a pH similar to that of seawater.

Transition zones

Data from the transition zone between the dead mangroves/salt-marsh and the mangrove forest shows the chemical influence of the trees on the sediment (**Figs.** 18, 19, 20, 21). Similarly, the transition zone between the mangrove forest and the tidal flats depicts the changes in chemical conditions between these two environments (**Figs.** 22, 23, 24, 25). For transects between the dead mangroves and the forest (T1H1 & T3H1), there is a marked decline in the soil pH from the dead mangrove into the forest, as well as a decline with increasing depth in the sediment. Values of pH greater than 8.3 suggest ammonification of the sediment by bacteria (especially noticeable in transect T3H1 where the pH reaches 9.3 -see **Fig.** 20).

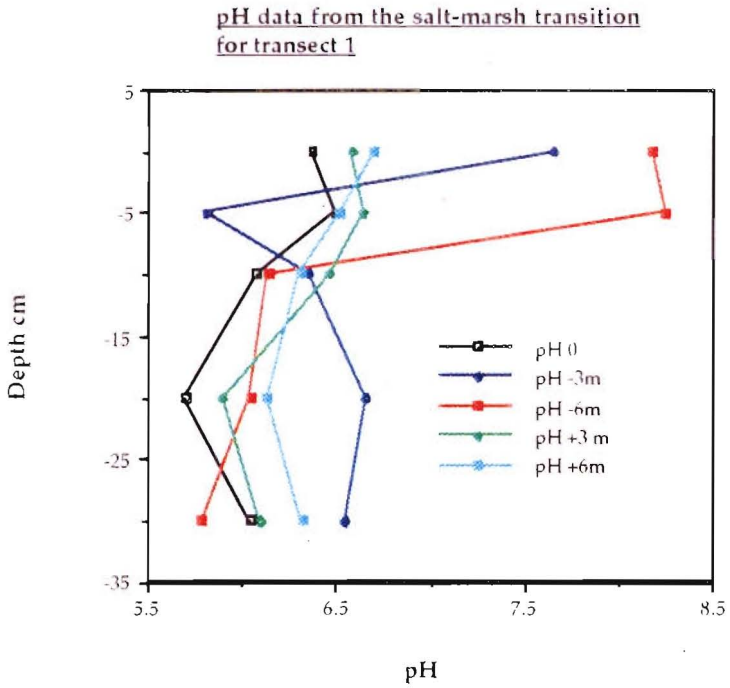


Figure 18 pH data from the dead mangrove/salt-marsh transition for transect 1. Values in the key -3, +6 m are distances from the edge of the mangrove forest; positive distances are in the seaward direction.

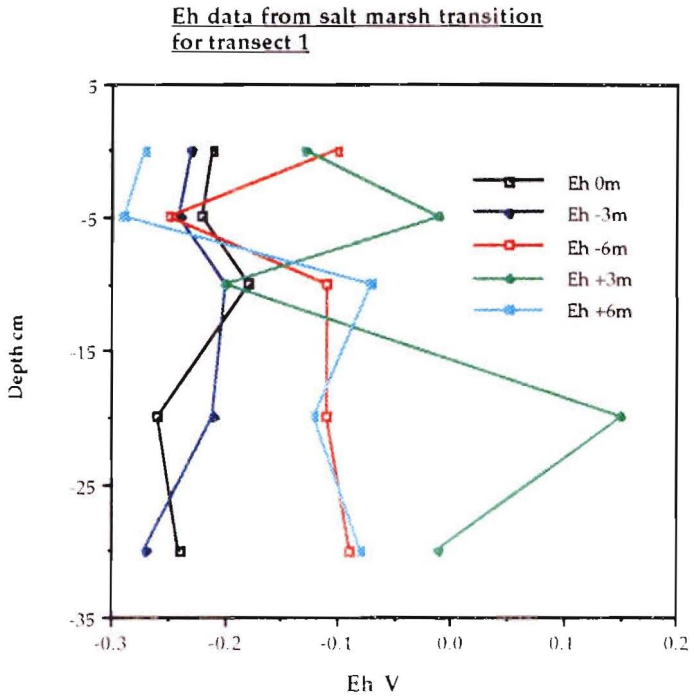


Figure 19 Plot of the Eh data from the dead mangrove/salt-marsh transition for transect 1. Values in the key -3, +6 m are distance from the edge of the mangrove forest; positive distances are in the seaward direction.

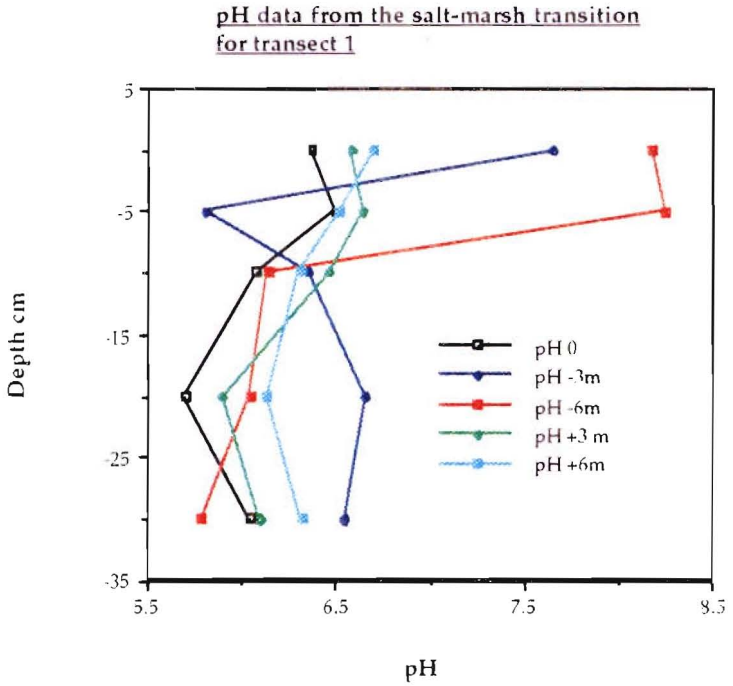


Figure 20 Plot of the pH data from the dead mangrove/salt-marsh transition for transect 3. Values in the key -3, +6 m are distance from the edge of the mangrove forest; positive distances are in the seaward direction.

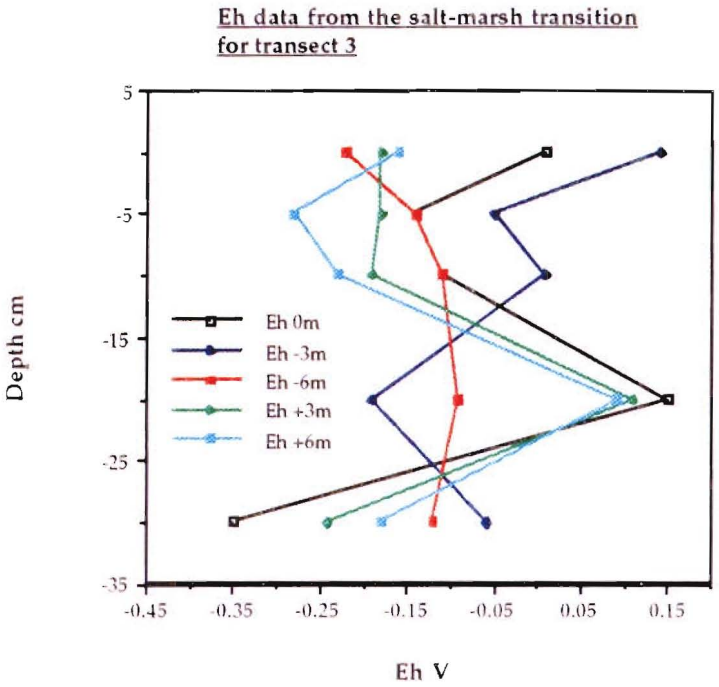


Figure 21 Plot of the Eh data from the dead mangrove/salt-marsh transition for transect 3. Values in the key -3, +6 m are distance from the edge of the mangrove forest; positive distances are in the seaward direction.

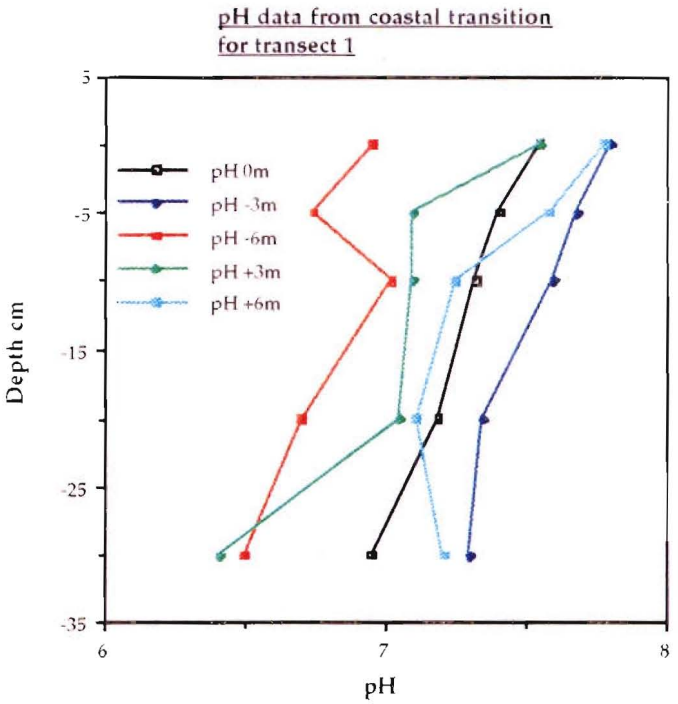


Figure 22 Plot of the pH data from the mud-flat transition for transect 1. Values in the key -3, +6 m are distance from the edge of the mangrove forest; positive distances are in the seaward direction.

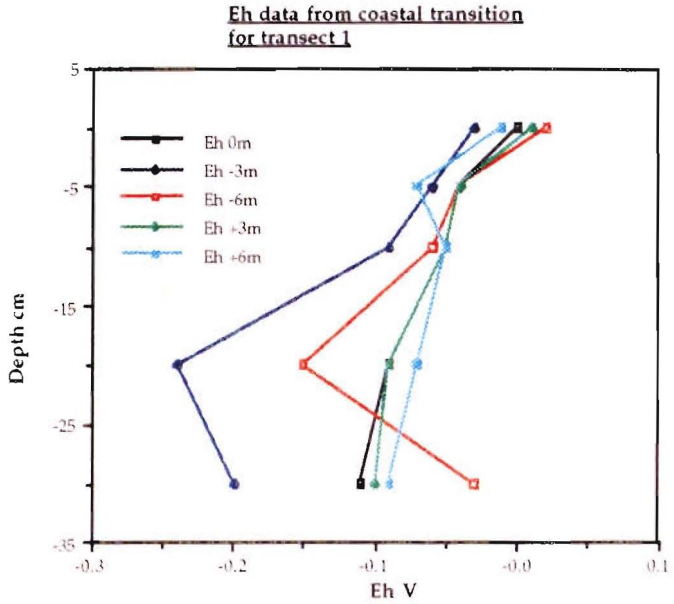


Figure 23 Plot of the Eh data from the mud-flat transition for transect 1. Values in the key -3, +6 m are distance from the edge of the mangrove forest; positive distances are in the seaward direction.

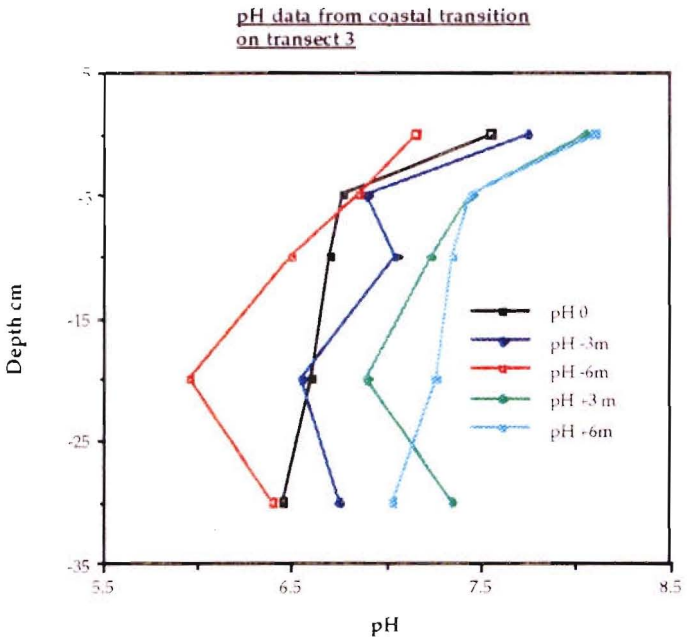


Figure 24 Plot of the pH data from the mud-flat transition for transect 3. Values in the key -3, +6 m are distance from the edge mangrove forest; positive distances are in the seaward direction.

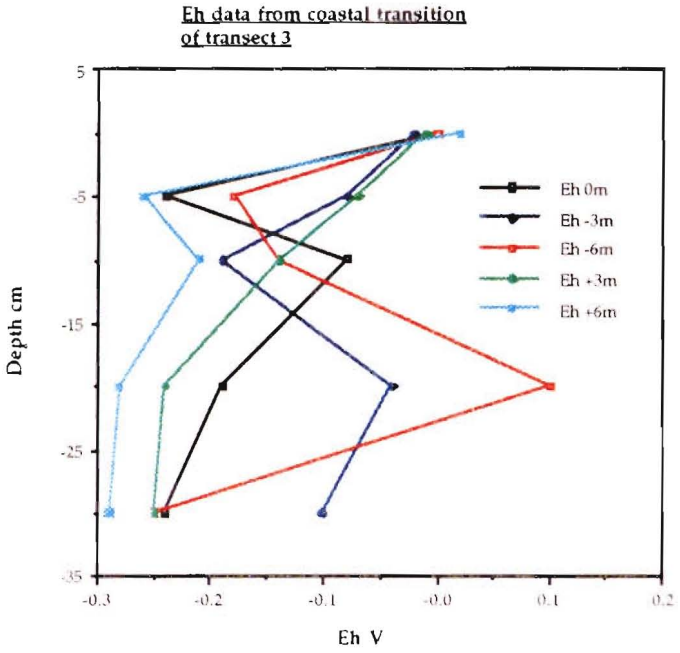


Figure 25 Plot of the Eh data from the mud-flat transition for transect 3. Values in the key -3, +6 m are distance from the edge mangrove forest; positive distances are in the seaward direction.

The Eh profile of T3H1 (**Fig.** 21) shows a sharp increase in Eh at a depth of 20 cm at distances of 0 +3 and +6 m into the trees indicating that the Eh of the sediment is raised in the tree-root zone. This increase is also seen in T1H1 (**Fig.** 19) for the +3 m hole, and to a lesser extent in the +6 m hole. The differences between the two transects is inferred to reflect the wetter more anoxic conditions (**Figure** 15) that prevail at the transition zone for transect 1. Associated with the increase in sediment Eh at the 20 cm depth is an appreciable fall in the pH (**Figs.** 18 & 20). The rise in Eh and fall in pH suggests that aeration associated within the trees causes oxidation of the sediments and production of sulphuric acid as a result of the oxidation of sulphidic material.

The data for the coastal transitions show similar trends to the salt-marsh transitions, in that holes from within the trees show a sharp increase in Eh at a depth of 20 cm for T3H2 and 30 cm for T1H2 (**Figs.** 23 & 25). Values of Eh

of the surficial sediments over the forest-mudflat transition are all very similar, indicating a stable chemical environment, in contrast to the surficial Eh from the forest-saltmarsh transition T1H1 and T3H1 (Figs. 19 & 21). Disparity between the two transitions is probably related to the abundant algae in the dead mangroves which raises the Eh for the -3 and -6 m stations; see Figs. 19 & 21.

Associated with the increase in the Eh in the forest-mudflat transition is a decrease in pH (Fig. 22 & 24), which is most noticeable for the -6 m station (furthest into the trees). Values of pH for this coastal transition show a gradual increase towards the sea as a direct response to the influence of tidal waters.

24 hour Eh/pH monitoring.

Data from the twenty-four hour monitoring of Eh/pH indicates that there are distinct chemical zones (Figs. 26, 27, 28, 29) in the areas; two of these zones- the dead mangroves and the salt marsh- are similar, and will be discussed together. All of the selected sites show some degree of confinement of chemical conditions with depth, though this confinement is less marked in the site from the irregularly flooded mangroves (core 3), where Eh/pH conditions are significantly different from the other areas (Fig. 28).

Chemical variations within sediments from the dead mangroves and the salt marsh are similar, with the dead mangroves showing a more gradual decrease in Eh/pH variability with depth over each 24 hour cycle (Figs. 26 & 27). At both locations, surficial sediments are covered by extensive algal mats; both a green algae and a pustular purple variety are present. Below these algal mats is a zone of black sulphidic and organic matter-rich sediments, with a strong smell of H_2S. Beneath these black sediments is a blue grey clay with iron oxyhydroxide mottles; the oxide staining indicates

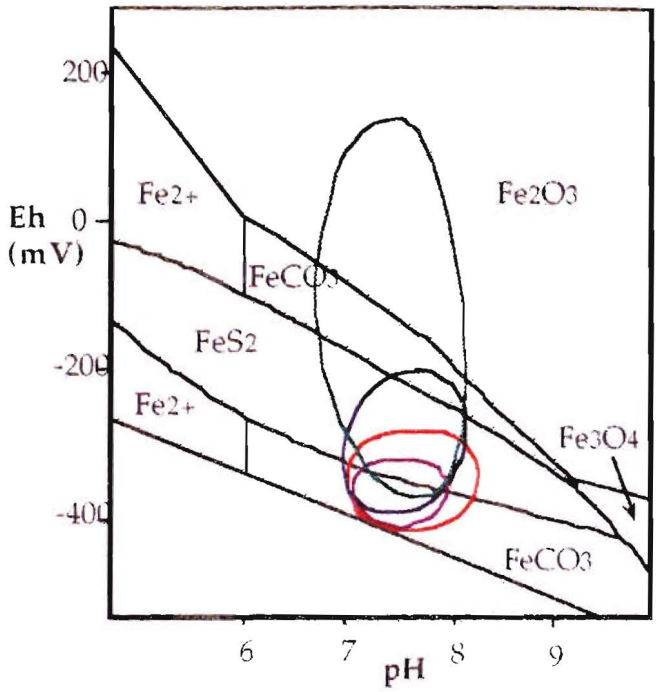


Figure 26 Plot of the Eh pH conditions for the surface, 2 cm, 4 cm and 10 cm depths in core 1 from the salt marsh. Colours are green surface, blue 2 cm, red 4 cm and purple 10 cm depths. The closed loops for each depth show the variation in Eh/pH conditions over a 24 hour cycle.

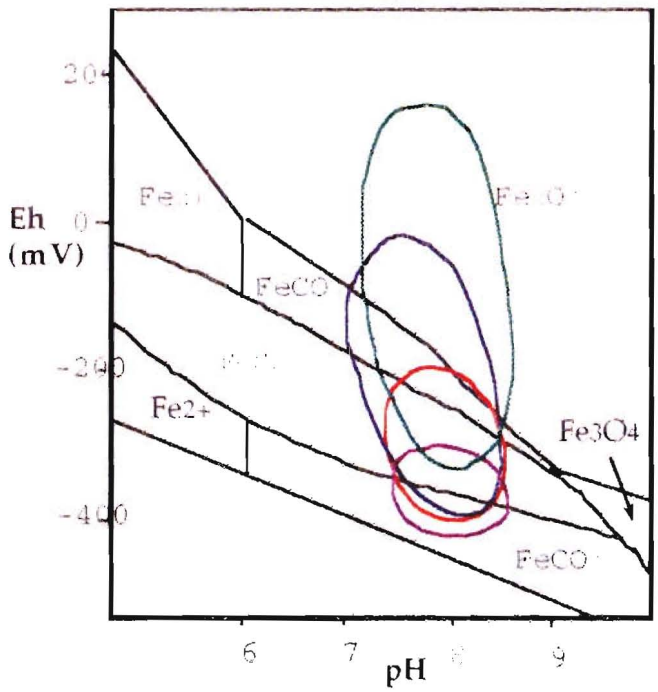


Figure 27 Plot of the Eh pH conditions for the surface, 2 cm, 4 cm and 10 cm depths in core 2 from the dead mangroves. Colours are green surface, blue 2 cm, red 4 cm and purple 10 cm depths. The closed loops for each depth show the variation in Eh/pH conditions over a 24 hour cycle.

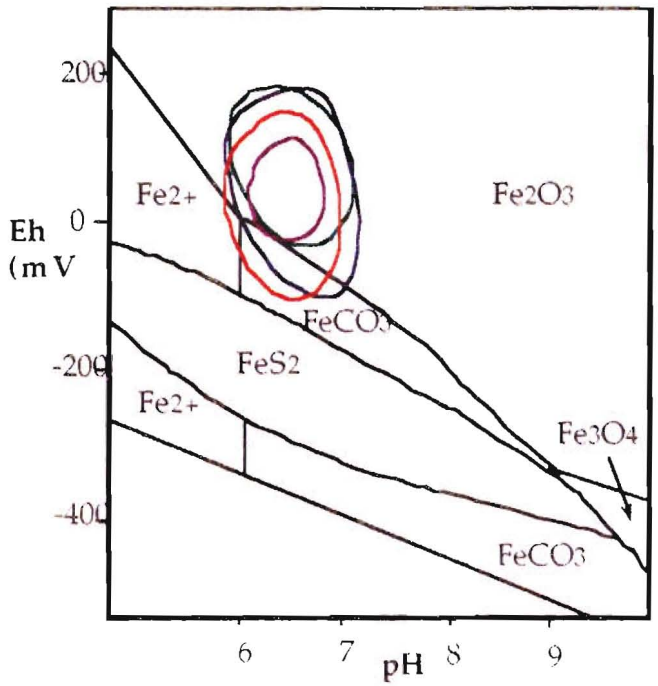


Figure 28 Plot of the Eh pH conditions for the surface, 2 cm, 4 cm and 10 cm depths in core 3 from the mangroves south of the road and just east of the southern tip cell. Colours are green surface, blue 2 cm, red 4 cm and purple 10 cm depths. The closed loops for each depth show the variation in Eh/pH conditions over a 24 hour cycle.

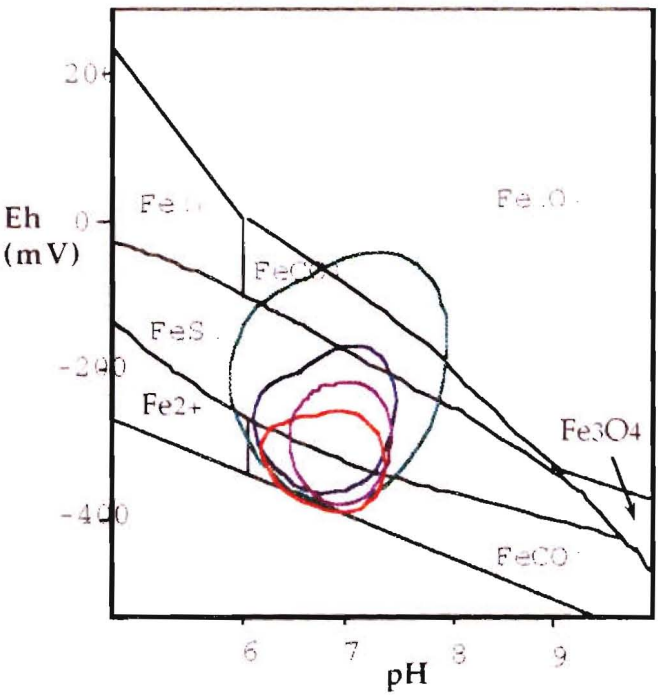


Figure 29 Plot of the Eh pH conditions for the surface, 2 cm, 4 cm and 10 cm depths in core 4 from south of the road at mean high water level. Colours are green surface, blue 2 cm, red 4 cm and purple 10 cm depths. The closed loops for each depth show the variation in Eh/pH conditions over a 24 hour cycle.

that the clay has undergone a period of oxidation and acid-sulphate production.

During the day the surface of the algal mat is covered with gas bubbles, indicating that the surface water is supersaturated with respect to oxygen. Oxygen production by the algae is believed to be responsible for the dramatic change in Eh/pH characteristics over the 24 Hr. cycles. Photosynthetic oxygen production during the day raises Eh and decreases pH, whereas respiration at night lowers the Eh and raises the pH. Differences between site 1 and site 2 are attributed to a greater density of algae and less consolidated surficial sediments in the dead mangroves, which results in a greater oxygen productivity and circulation to the lower parts of the sediment. The higher algal density and less consolidated sediment also results in a greater capacity for the sediment to buffer the decline in Eh during periods of respiration, hence the more gradual confinement of Eh/pH loops within the sediments from the dead mangroves (Fig. 27).

Data from the irregularly flooded mangroves (site 3, **figure** 28) show that this area is very different to the other three. The surface sediment is a veneer of yellow clay transported into the area by storm-water runoff from the tip; below this yellow clay the sediment is dominated by a blue-grey clay with yellow mottles that contains the mangal root mat.

The Eh at site 3 is higher and less variable than in other areas (**Fig.** 28), while the pH is lower (pH 6.0-6.5 compared to 7.5-8.0 for the salt-marsh and the dead mangroves). The irregular flooding at this site allows replacement of water-filled pores with air, and consequently the sediment is well oxidised (high Eh) and the oxidation of sulphidic results in the decrease in pH. This effects of sediment oxidation are more clearly demonstrated about 20 m from this sampling site, where Eh is about +250 mV and pH falls to about 4.5 (see Figures 15 & 16).

Site 4 is characterised by unconsolidated blue-grey silts and muds resting on mangal root-mat. Below this root-mat are more consolidated blue-grey clayey and sandy-silts. Poor consolidation of the surficial sediments primarily results from the regular tidal inundation of the site. At this site, algae are not as abundant as the algae in the dead mangroves and the salt-marsh. The algae at this site is able to provide oxygen during the day to raise Eh, but the rise is not as marked as the rises at sites 1 and 2. At depth, the Eh/pH characteristics of the sediment become less variable over 24 hrs, but a respiration-photosynthesis cycle is still clearly evident, even at a depth of 10 cm (Fig. 29). The wide variation in pH at the surface at this site is possibly due to auto-oxidation of sulphides during photosynthesis (decreasing pH), followed by a period of bacterially-mediated ammonification, which causes pH to rise in conjunction with the rise in Eh. During respiration, loss of ammonia to the atmosphere should lower pH, but re-precipitation of sulphides will tend to keep the pH high.

Chemical Analysis Data

Metals in sediments

The analytical data from the Wynnum area are plotted using Cricket Graph® 1.3.1. Inspection of the data indicates that there are two groupings of metals, which are best explained in terms of their Lewis acid/base properties (i.e., whether the metal forms a hard or soft ion). Hard acids have a higher charge-to-size ratio whereas the soft acids have large cations of low charge.

Analysis of tin was conducted only on total extractions; the decision not to analyse tin for the sequential data was due to the poor sensitivity for tin by the atomic adsorption procedure; the poor sensitivity and high dilution factors casts doubt on the absolute concentrations of tin found in the sediments, because a small deflection in the reading results in a large

deflection in concentration within the sediment. Despite these problems, tin data does show a trend and was kept to aid understanding of the geochemical processes occurring at the Wynnum site .

Lateral variations at Wynnum

Lateral distribution patterns for metals at the Wynnum site (**Figs.** 30, 31, 32, 33 & 34; also see **Appendix** 4) are irregular, with many of the transects showing a distinct humps in their profiles. These distributions are different from those originally found by Saenger, McConchie and Clark (1991; see **Appendix** 5) due to the unusually dry climatic conditions that have prevailed in the Wynnum area over the sampling period. Prolonged dry conditions result in a downward redistribution of metals in the sediment column and the lack of leachate input would be expected to mask the trends found by Saenger, McConchie and Clark (1991).

Saenger, McConchie and Clark (1991) found that metal concentrations in the sediment fell with increasing distance from the tip in a generally exponential fashion. The only transect in this current work that shows this trend is Transect 1, where metals decay exponentially at the 30 cm depth (**Fig.** 30). However, some of the high concentration metals are unchanged and some of the low concentration metals have one or more irregularities on their trends. Mercury for the 30 cm depth (**Fig.** 30A) shows some increase in concentration at the coast. At the 30 cm depth, the graph is dominated by the massive zinc load of 600 ppm.

When the data are viewed in relation to the Eh map (**Fig.** 14), some of the trends become more obvious. The Eh diagram shows that Transect 1 runs parallel to the reduced Eh zone that marks the drainage line for the dead mangroves. This low Eh zone has probably resulted in immobilisation of many of the metals, thus preserving the exponential character of the transect despite the cut off of leachate supply. On the sediment surface, the trend is

irregular and the data show that both the anomalous rises in metal concentration, occur in or near depressions which are characterised by low Eh values. Thus the break-down of the exponential distribution trend is a result of the climatic conditions that have lead to drying of the sediment, oxidation and the mobilisation of metal species.

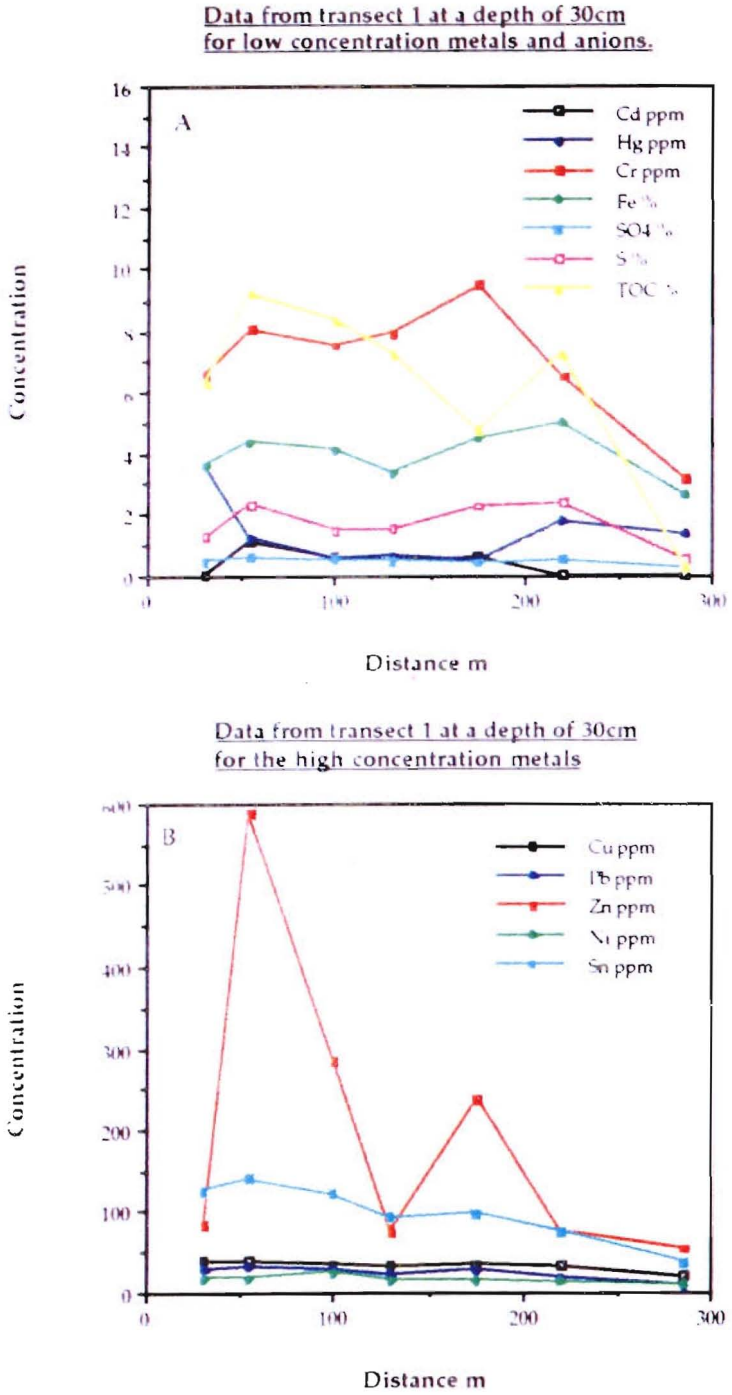


Figure 30 Plot of the total analysis data for transect 1. Graph A is a plot of the low concentration metals, anions, and total organic carbon (TOC). Graph B is a plot of the higher concentration metals.

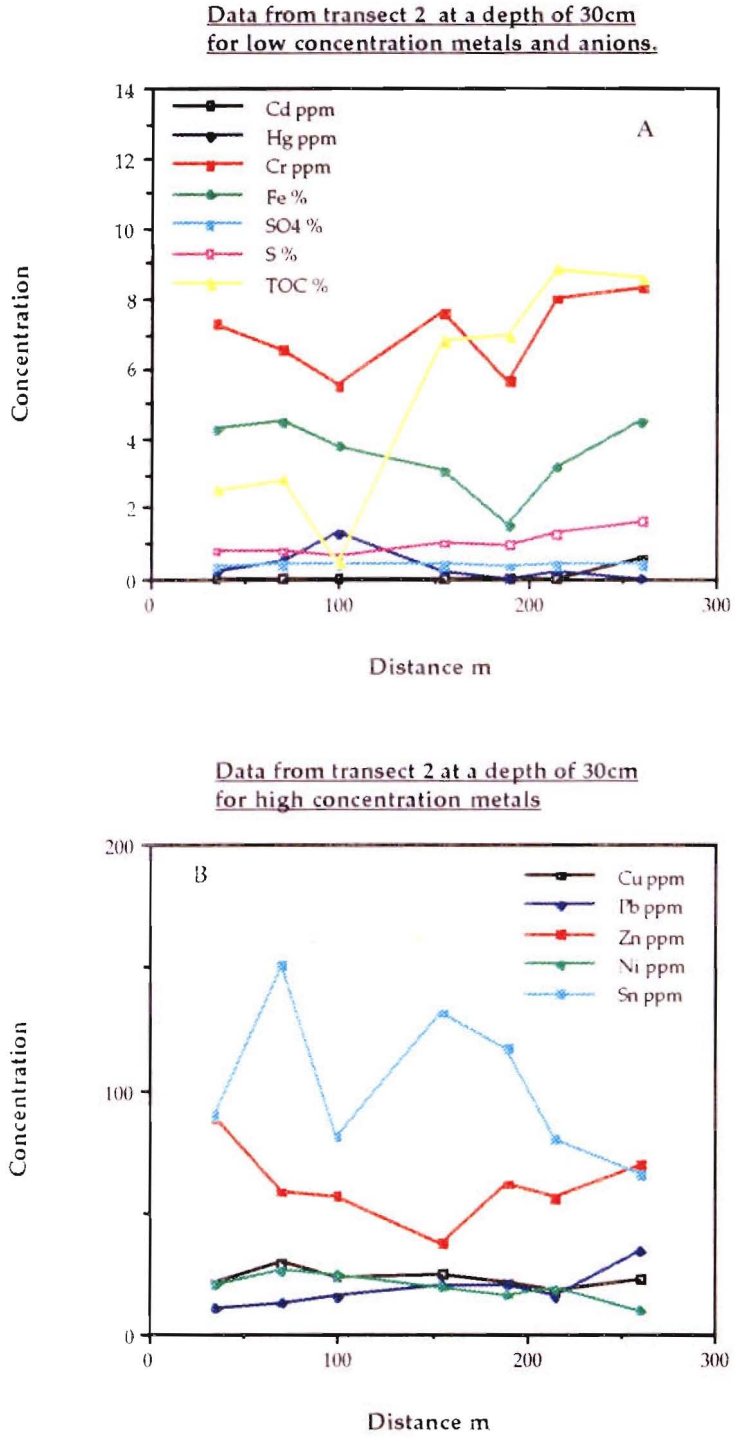


Figure 31 Plot of the total analysis data for transect 2. Graph A is a plot of the low concentration metals, anions, and total organic carbon (TOC). Graph B is a plot of the higher concentration metals.

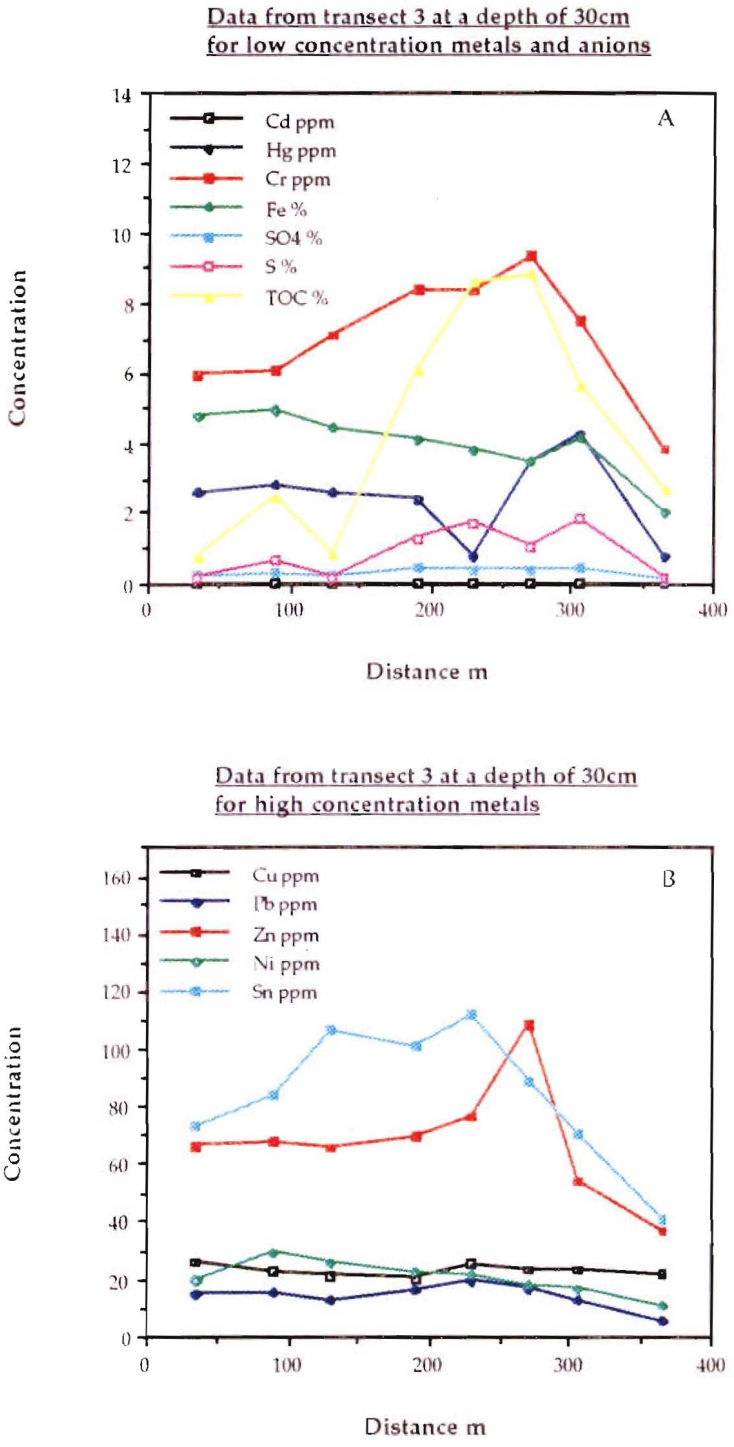


Figure 32 Plot of the total analysis data for transect 3. Graph A is a plot of the low concentration metals, anions, and total organic carbon (TOC). Graph B is a plot of the higher concentration metals.

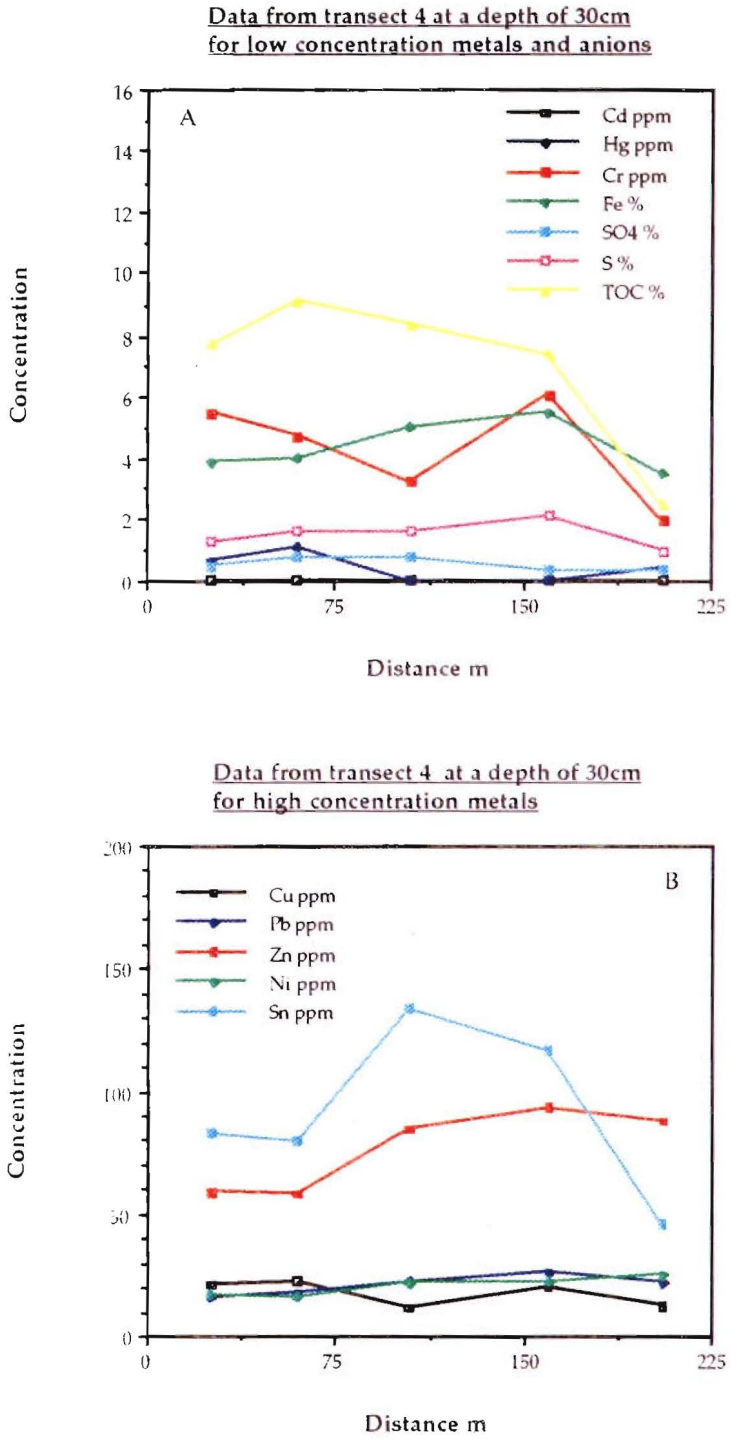


Figure 33 Plot of the total analysis data for transect 4. Graph A is a plot of the low concentration metals, anions, and total organic carbon (TOC). Graph B is a plot of the higher concentration metals.

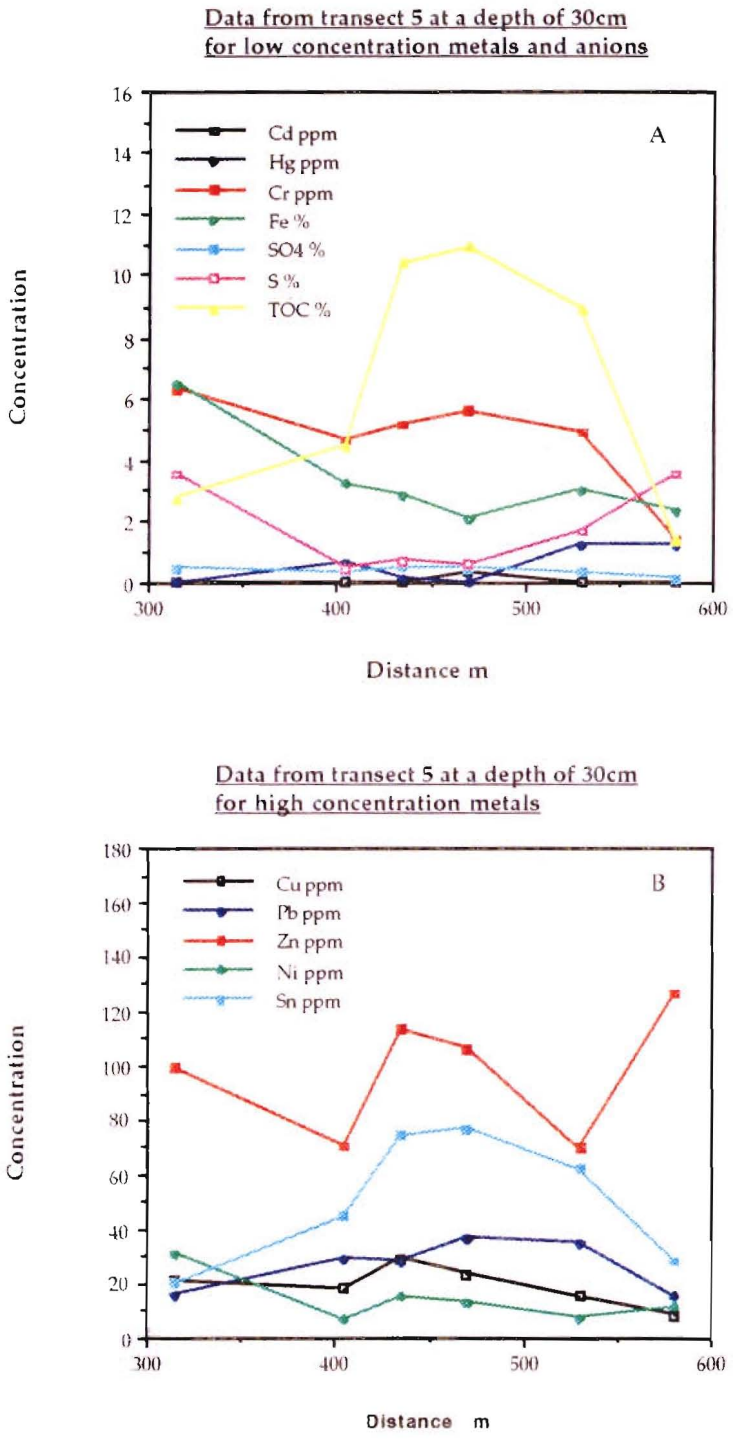


Figure 34 Plot of the total analysis data for transect 5. Graph A is a plot of the low concentration metals, anions, and total organic carbon (TOC). Graph B is a plot of the higher concentration metals.

Trends for the second transect confirm the importance of low Eh holes depressions retaining otherwise mobile metals. However these depressions, while capturing some metals, are not totally effective for all (e.g. zinc in the surficial sediment of transect 2; Fig. 31). Zn shows a curiously large increase in concentration in the last sampling site (about 30m from the edge of the trees), indicating that some of these mobilised metals are reaching the coast.

Transect 3 (Fig. 32) also indicates the remobilisation of metals (especially Zn), and a major spike in zinc concentration is evident in the forest zone. This spike has advanced further from the tip in the deeper sediments than in the upper sediments due to the more persist water saturation.

Transect 4 (Fig. 33) shows that in the area of high Eh and low pH, metals have been have mobilised under oxidising conditions and have been stripped from the area. The movement of the mobilised metals down the hydraulic gradient has produced rise in metal concentration at about 150 m from the site for the surficial sediments and about 100 m for the sediments at depth; iron and sulphur show a substantial increase in concentration at the distances. The arresting of metal migration from zone of acid sulphate soil formation is primarily due to the Eh gradient; as the Eh decreases towards the coast there is a corresponding rise in metal accumulation.

Transect 5 (Fig. 34) shows that metal concentrations in the surficial sediments in the dead mangroves increase toward the south suggesting that there is a general southerly hydraulic gradient. When the transects change bearing towards the coast, metal concentrations in the sediment decreases toward the coast. As with the other transects, metal concentrations along transect 5 show a few concentration peaks that are again related to the migration of the metals and accumulation in areas of low Eh. At a depth of 30 cm , Zn, Hg and S show a sharp rise in concentration at the coast, which may be due to the proximity of the sewage outfall to this sampling site.

Though the above discussion has primarily focussed on Zn, similar trends can be seen with other metals although they are generally less clear because Zn is more mobile and more abundant than other metals in the area.

Total organic carbon from all the transects clearly define the presence or absence of trees; even in the organic matter-rich dead mangrove area, a sharp increase in the TOC content is evident as the boundary between these environments is crossed.

Stratigraphic variations at Wynnum

Stratigraphic variations in some of the 12 cores taken from the Wynnum area are plotted in Figures (35, 36, 37; also see Appendix 4), which show that there are the two types of metal behaviour in the sediment: those metals that act as hard ions (Zn, Cu, Sn, Ni, Cr & Fe) and those that act as soft ions (Pb, Hg, Cd and sometimes Cu & Sn). The periodic switching of behaviour of Cu and Sn is a function of the oxidation state of each ion; in the reduced state the metals are soft, whereas in more oxidised conditions the metals act as a hard ion.

The concentrations of the hard metals closely parallells the trends in sulphide concentration, indicating that these metals are precipitated as sulphides. Soft metals ions show a decrease in concentration from the surface sediments to deeper sediments, which suggests that surficial waters distribute the metals laterally over the area, and that they are bound by adsorption. One of the most likely binding-processes is the combination of the metals with organic matter, because organic matter is a large soft anion which will bind preferentially with soft cations, whereas the hard anions (e.g., chloride) will preferentially bind with the hard cations (Huang *et al.*, 1987).

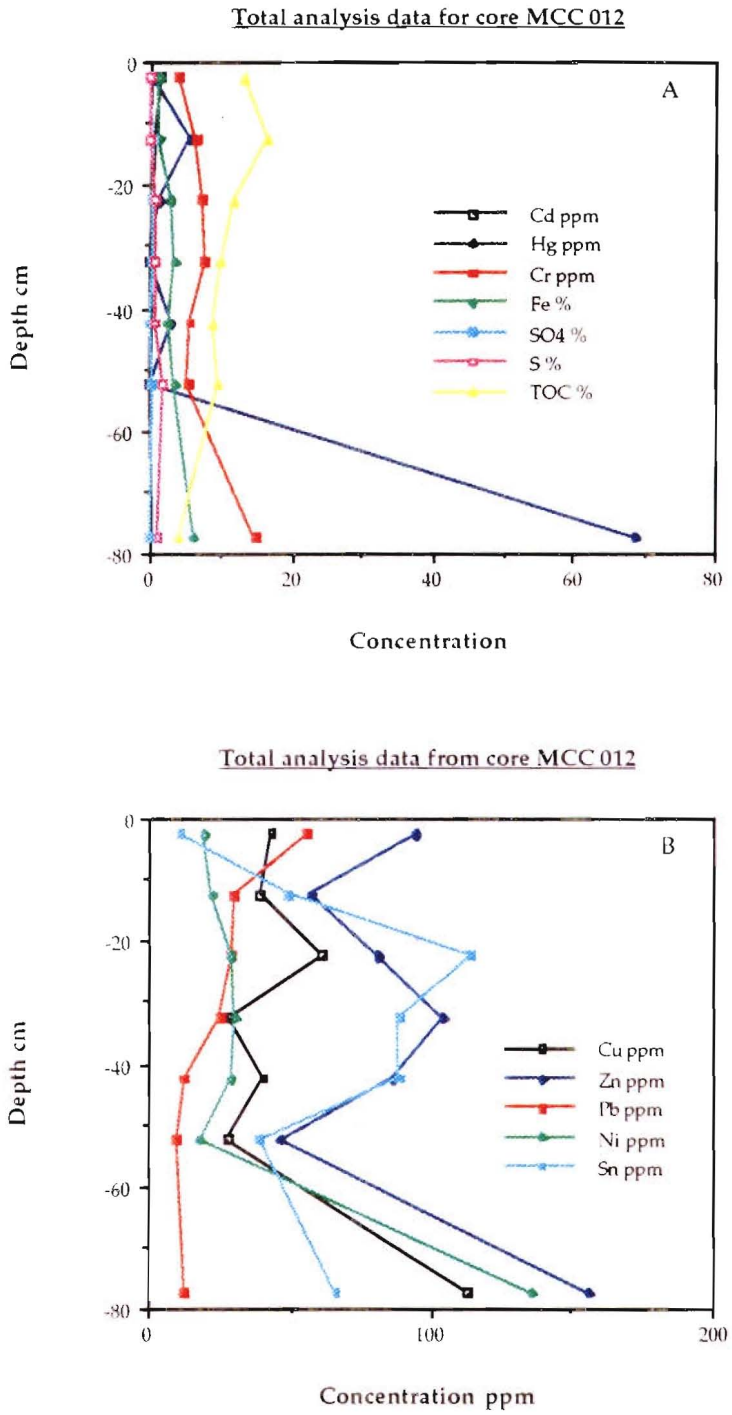


Figure 35 Plot of the total analysis data from core MCC 011. Graph A is data for the lower concentration metals, the anions and the total organic carbon (TOC) analyses. Graph B is a plot of the higher concentration metals.

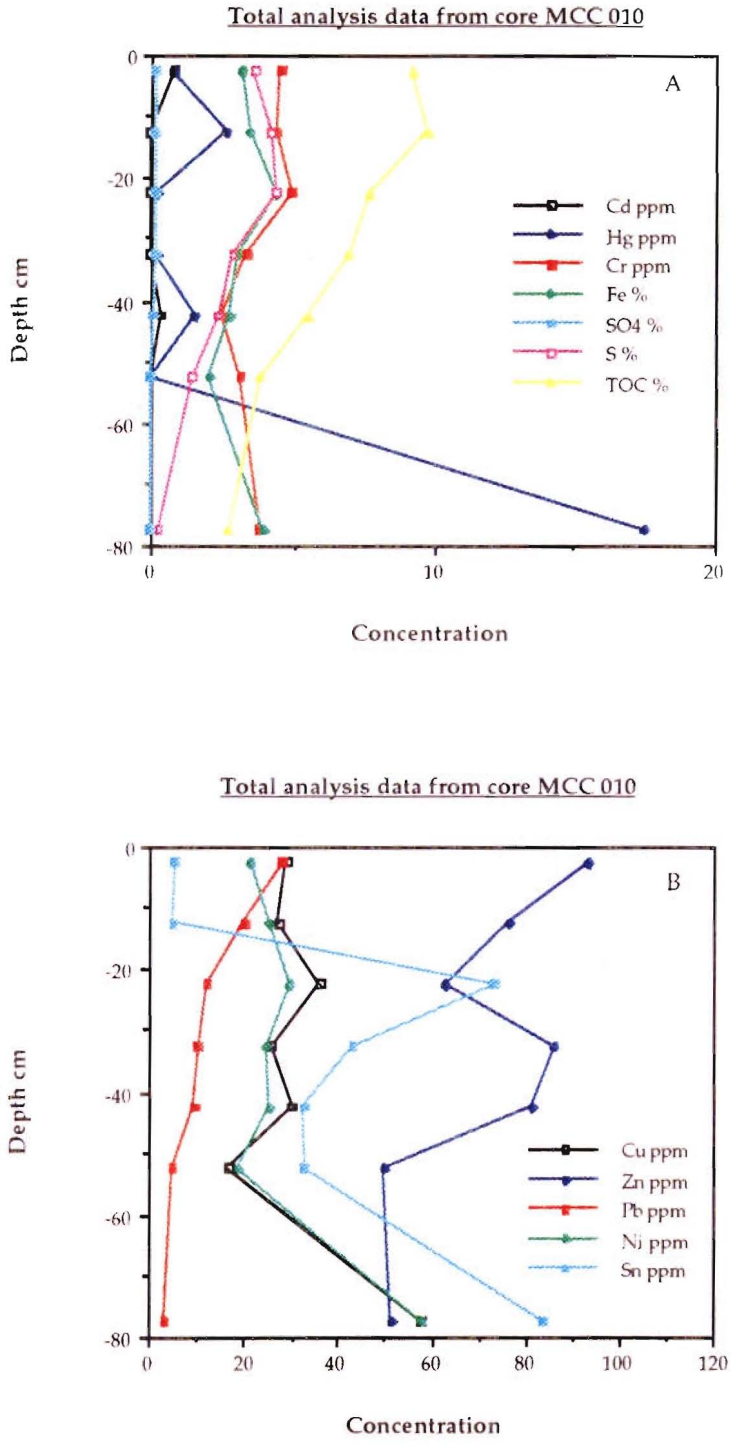


Figure 36 Plot of the total analysis data from core MCC 010. Graph A is data for the lower concentration metals, the anions and the total organic carbon (TOC) analyses. Graph B is a plot of the higher concentration metals.

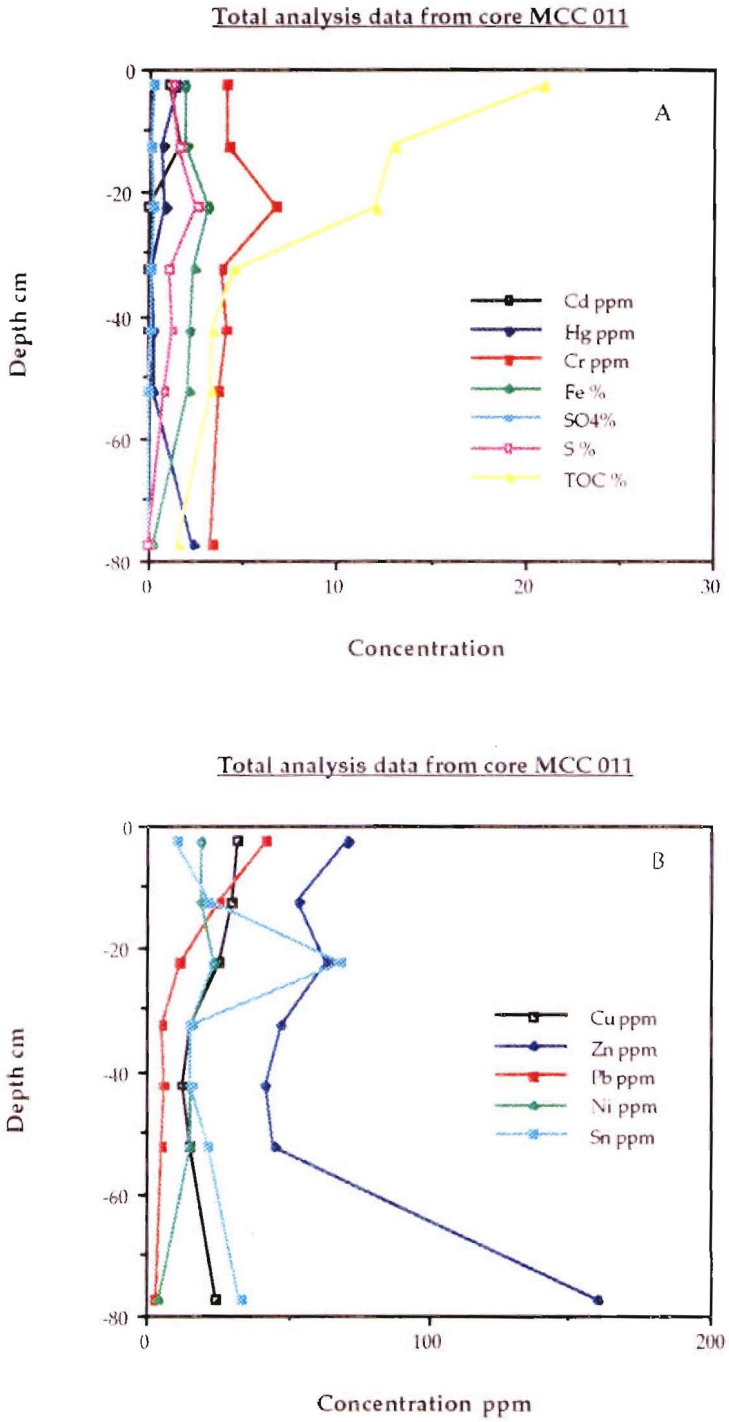


Figure 37 Plot of the total analysis data from core MCC 011. Graph A is data for the lower concentration metals, the anions and the total organic carbon (TOC) analyses. Graph B is a plot of the higher concentration metals.

Core MCC 012 (Fig. 35) shows the effect of the weathered basalt beneath the sediment, which has elevated concentrations of all metals, except Pb and Cd, compared to samples from the overlying sediment. The high metal concentration in the top of the weathered basalt is thought to reflect the migration of tip leachate across the top of the impermeable basalt basement. Core MCC 010 (Fig. 36) also shows this with a sharp rise in metal concentration in the top of the weathered basalt, but core MCC 011 (Fig. 37), does not show a similar sharp rise in concentrations probably as a result of mineralogical differences in the weathered basalt at the site and is thought to reflect a change in mineralogy of the basalt (see **Appendix** 1). The weathered basalt in cores MCC 012 and 010 contains small amounts of smectite clays, decomposing feldspars and other accessory minerals, whereas in core MCC 011 it is almost exclusively quartz and kaolinite (fig. 3 and **Appendix** 1).

The sequential data indicate that soft metals ions are more extractable in the early phases of extraction than are hard metal ions. With the Gillman-Sumpter, acetate, and dithionite extractions the solutions often contained dissolved organic matter and it is likely that the soft metals are bound to this extractable organic matter. This trend is very noticeable for mercury especially for samples such as MCC 001/4, MCC 004/2 & 4; (see **Appendix** 2).

For metals with a hard ion Lewis acid behaviour, the largest amount of the metal is extractable in the aqua regia (most resistant phase see **Appendix** 2). Because the concentration of iron at the Wynnum site closely parallel the sulphide content down the cores, it is likely that much of the iron is present as sulphide phases and it is equally likely that these hard metals are incorporated into the sulphide lattice, or present as other metal sulphides.The mobilisation of some iron in the dithionite extracts indicates that some iron is also present as oxides; the concentration of dithionite-extractable iron is highest in the upper (more oxidised) portions of the cores

and decreases with depth (Appendix 2).

Metals in waters

Surface waters

Data from the surface water analyses show that metals are strongly partitioned between the sediment and ground water phase. While the surface waters show similar metal concentration trends to the surface sediments the concentration of metals in the ground waters was 1000 times lower than in the sediment for the same sampling site. Clearly the extraction mechanisms for transferring metals from the water to the sediment are very efficient. As indicated by the lateral distribution of metals in the sediments it is possible that these groundwaters, despite their low concentration of metallic species, appear to play an important role in the transport of metals through the area.

A seepage of what is believed to be tip leachate was ponded on the road that subsequently created of a bog (locality X figure 14). The area of seepage was excavated and two samples of this water and a sample from the pooled water on the road were taken. Another area of seepage was located on the eastern slope of the tip cell and a sample taken from this seep. Several other small seepages were also located, but a lack of adequate flow from them prevented more samples being collected.

The two samples from the southern seep show elevated metal loads compared to surface samples taken within the mangroves, but these were much lower than concentrations in the seep from the eastern side of the tip; the the only surface water sample in which any cadmium was detected was from the eastern seep. Waters from both sites developed an oily surface to the water within a few minutes of exposure to the atmosphere; this oily surface film is believed to be a product of photo-degradation of dissolved organic matter in the water.

The sample taken from the road had a much lower metal content than the

seepage that is feeding it, suggesting that metal adsorption by the sediments is rapid, and can occur over short distances. There is an adsorption of as much as 98% of metal species present in the original seepage over a distance of about 10 m .

Three surface runoff samples were taken from the site in January 1992. These samples showed high concentrations of metals compared with samples from within the mangroves. A further sample from the leachate drain showed concentrations of Cr, Pb and Ni to be higher than the runoff sample but Zn, Fe, Cu and Hg were lower. There is some doubt about the effectiveness of this leachate drain, because seepages to the south and east of the tip have not been intersected by the drain and continue to flow.

The input of metals to the mangroves by direct seepage and the inputs via runoff of rainwater are high. The input can be roughly calculated for the Wynnum area based on a runoff area that directly feeds the salt-mash and the dead mangroves from the northern tip cell of 29 700 m^2. For every 100 mm of rainfall 100 lm^{-2} of water is deposited and if it is assumed that 25 % of this water will be runoff, then 742 500 l of water will enter the salt-marsh and the dead mangroves. Averaging the data for the runoff samples would indicate that for every 100 mm of rainfall: 2.58 g of Pb, 7.63 g of Cu, 52.28 g of Zn, 0.01 g of Hg, 0.05 g of Cr, 7.08 g of Ni and 146.2 g of Fe would be transferred from the tip. Given that this process has been happening for 15 years with a rainfall of about 1200 mm yr^{-1}, then the figures quickly become kilograms.

Groundwaters

Monitoring of the groundwaters at the Wynnum site reveals that as the dry season progresses, the concentration of metals in the groundwaters falls with the increasing length of dry periods. The sampling program was designed to run for 4 months and it was fortuitous that there was a

significant fall of rain before the end of the sampling period. This fall was heavy in the Wynnum area (R. Hughes, Department of Environment and Heritage, Queensland. pers. com.), but it was localised and not recorded at the Airport (**Appendix** 3). Samples taken from the area 3 days after the event show that piesometer 1, closest to the tip, experienced a high flush of metals from the tip (Fig. 38).

Considering the long dry period preceding this event, this spike indicates that the metals in the ground water are linked to the leaching of the tip by rain water. Samples taken in early 1992 show that metal loads had fallen back to the levels of the dry season. Initially, it was expected that the amount of metal leaching from the tip would be highest during the wet season. The data shows that the metal concentration per unit volume similar in both seasons, but the total volume of water passing through the system during the wet season is much greater.

Groundwater monitoring over a tidal cycle reveals that there is minimal mixing of saline groundwater and the waters of the tidal wedge. For the southern piesometer line, the two piesometers closest to the coast show the influence of the incoming tide: ground-water rises and the salinity falls. For piesometer 4, (closest to the tip) there is a rise in ground-water height, but there is also a rise in ground water salinity indicating little mixing of the more saline ground-water with the incoming tidal waters (Fig 39). The observation that there is little or no mixing of tidal and groundwaters within the study area may have implications for the dispersion of metals through the groundwater.

The changes in groundwater for the northern transect are more difficult to interpret than those for the southern transect. Piesometers 2 and 3 show a salinity fall at the position of the high tide, but this fall is not reflected in a rise in water table height, which seems to lag behind the salinity by several hours. This lag suggests that the sediment in the northern transect are less

permeable than they are to the south. The water table height in piesometer 1 shows this lag in maximum height relative to the tidal maximum, and although the groundwater salinity starts to rise with the tide as in piesometer 4 it continues to rise further as the tide falls.

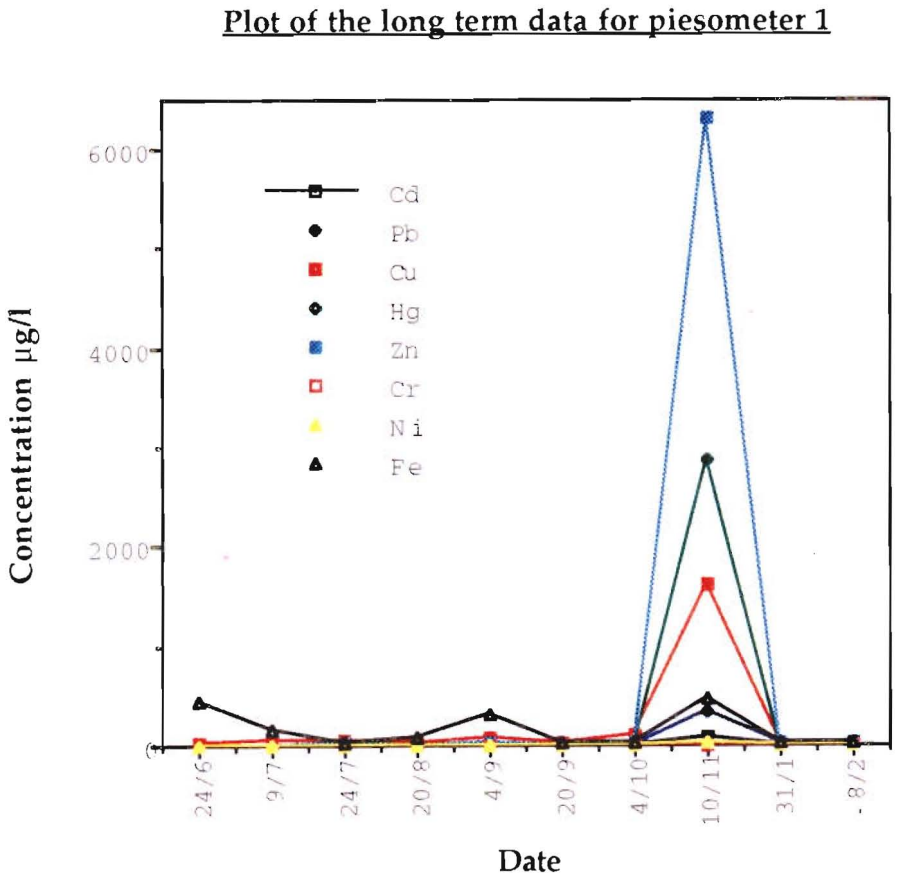


Figure 38 Graph of the long term chemical data from piesometer 1. The large spike of metal was preceded by a significant fall of rain about 3 days prior to sampling.

Metals in biota.

The analysis of metals in mangrove plants (Saenger, McConchie & Clark, 1991; see **Appendix** 5) indicates that there is a relationship between the metal load in the plants and the environmental metal load. Data in this study show that there are no significant correlations between the plant-available metals and the total organic carbon content, iron content, sulphide content or clay content of the sediment, but there is a correlation between the plant available

metal and the total metal in the sediment (**Fig.** 40).

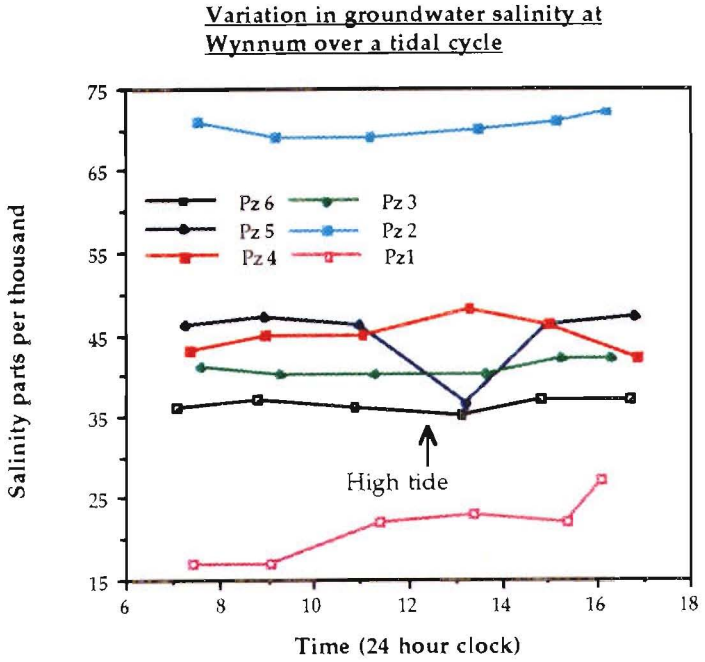


Figure 39 Plot of the variation in groundwater salinity for the Wynnum study site over a tidal cycle.

The lack of correlation between plant available metal loads and the sediment characteristics (mineralogy and bulk composition) indicates that there is no simple mechanism for metal release, and that no single factor controls this process.

Furthermore there was no correlation between the plant-available metal load in the sediment and the metal loads found in plant tissue. Several of the correlations showed a coefficient between 0.4 and 0.8 but none of these were statistically significant. These data show that the plant available metal load alone is not controlling the accumulation of metals in the plants; there are clearly other factors involved. Possibly additional influences include the action of the salt exclusion and metabolising membranes in mangroves (Saenger, McConchie & Clark, 1991), limitations on which stratigraphic horizons are tapped for nutrient ions by the mangrove root system, and the fact that the mangrove plants have sampled the environment over a much

larger period than this study, which as previously noted coincided with an anomalously dry season.

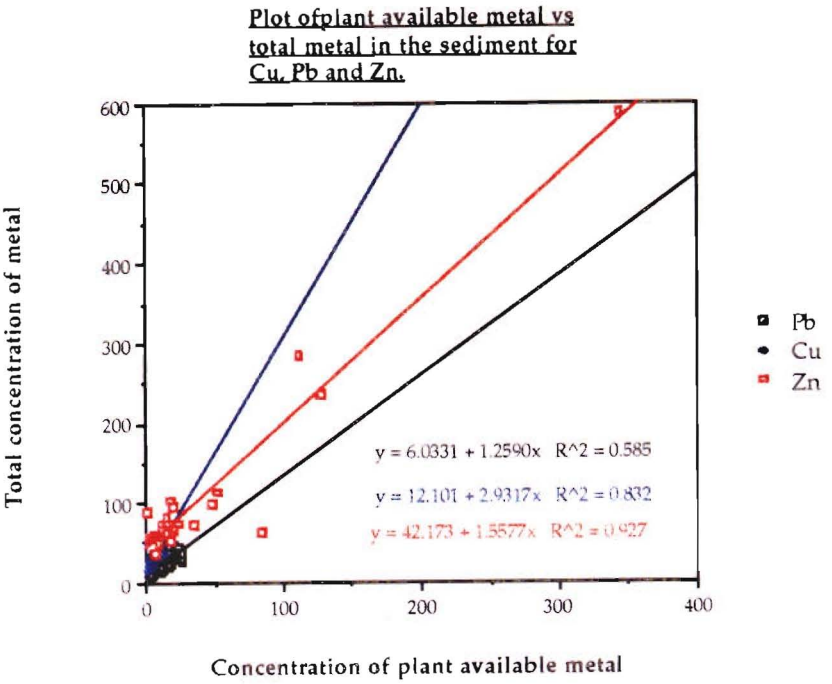


Figure 40 Plot of plant available metal and the total metal in the sediment at the Wynnum site.

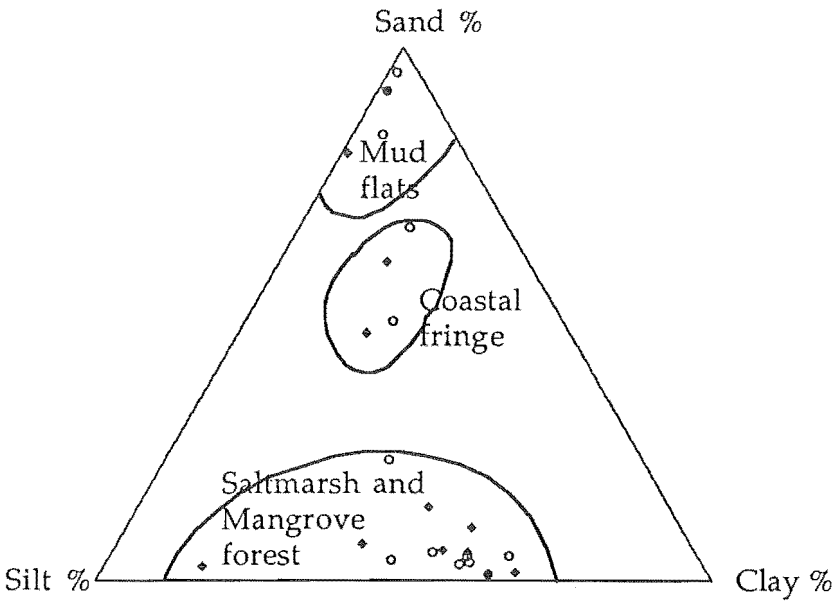
Grainsize analysis

Random samples from the field area were analysed for grainsize distribution trends. The data show that the mud flats have the coarsest detrital gain popu[illegible]ion, and the mangrove forest sediments have the highest clay content. The change in distribution is very evident between the mangroves and the mudflats (**Fig.** 41).

The difference in sediment grainsize between the two areas has a significant impact on the binding of metals; several authors (e.g., Förstner, 1989; Salomons & Förstner, 1984; and Harbison, 1986) have shown that the coarser grain sizes (e.g., sand fraction) play little role in the binding of metals to the sediment; and that the clay fraction has the greatest influence. This relationship exists because sandy sediments have a lower surface-area-to-volume ratio, and a lower charge to mass ratio, and thus a reduced ability to

bind metals. The effect of sediment grainsize is reflected in the metal concentrations along transects 1, 3 and 5 where metal concentrations fall at the boundary between the mangroves and the mudflats.

The data show that the sediments of the Wynnum area are slightly coarser at depth than they are near the surface (**Fig.** 41). This fining-upward trend in the sediments reflects the changing conditions as mangroves colonise the area and moderate wave action resulting in accumulation of increasingly finer sediment. The Ternary plot (**Fig.** 41) shows that there are three distinct sedimentary zones; the mud flats, the fringing trees where some coarse sediment is present, and the remaining mangroves and salt-marsh.



Ternary plot of the grain size data from the Wynnum Tip site

Figure 41. Ternary plot of the grain size data for the Wynnum area. Filled diamonds represent data from the 30 cm depth and open circles represent data from the upper 5 cm. A filled circle indicates values that are the same at both depths.

DISCUSSION

Biological Controls on Sediments

Biological controls on sediments at the Wynnum site include accumulation and stabilisation of sediments by the mangroves, establishment of micro-habitats for growth of algae and bacteria, and the affects of burrowing organisms on the sediments. Although there may be some direct metal uptake by biota, most of the biological controls influence metal behaviour indirectly by changing the geochemical conditions in the environment (e.g., Eh), by producing metal binding substances (e.g., decomposition products with a chelating capacity), by aerating the sediments by burrowing or root penetration, or by creating new subenvironments (e.g., by influencing drainage). For example, bacteria involved in the decomposition of organic matter do not effect the speciation of Cd directly, but some decomposition products readily complex Cd and the decomposition reactions commonly alter both pH and Eh.

Role of the mangroves

The distribution of mangrove species at the site is influences by tides (Stevens & Rogers, 1979; Dowling, 1986; and Hutchings & Saenger, 1987). Dowling (1986), and consequently there is a distinct zoning of mangrove species parallel to the coastline (Stevens & Rogers, 1979; and Dowling, 1986). *Avicennia marina* (Grey Mangrove) is predominant as a pioneer species which becomes established when enough siltation has occurred to enable growth of seedlings.*Rhizophora stylosa* (Spotted or Red Mangrove) can also act as a pioneer species, but around the Moreton Bay area it normally occurs behind the *Avicennia* fringe (Stevens & Rogers, 1979). Other species such as *Ceriops tagal* are common in the moderately wet parts of the forest and *Aegiceres corniculatum* (the river mangrove) and *Excocaria agallocha* (the milky mangrove) are abundant in drier parts of the forest.

Trapping and binding of sediment

The presence of mangroves results in increased sedimentation because the pneumatophores trap floating debris and act as a baffle to slow down water currents. Mangrove roots have adapted to the three major growth problems associated with coastal sediments: saltwater, anoxia, and the weakness of an unconsolidated substrate; different species have developed differing root adaptions to cope with these problems. Most mangroves posses a laterally-spreading root cable system with smaller vertically descending anchor roots which carry fine nutritive roots. Though the root system is shallow (< 2 m.), there is a high-below ground to above-ground biomass ratio exists (Hutchings & Saenger, 1987).

Different species of mangrove also posses different above ground root systems all of which can influence sediment trapping and binding (**Fig** 42). These include: (1) pneumatophores, which rise from the cable roots as small conical projection; (2) knee roots, which are modified cable roots which bend up out of the sediment and then dip back again; (3) stilt roots, which grow out and down from the trunk into the substrate; (4) buttress roots, which are similar to stilt roots but flatten into blade-like structures; (5) aerial roots, which are similar to stilt roots but are generally unbranched and not usually in contact with the sediment (Hutchings & Saenger, 1987). All of these above-ground roots that provide aeration for the subsurface roots which anchor the plant (Hook & Scholtens, 1978) and will tend to raise the Eh of adjacent sediment. Extensive development of above-ground roots significantly to reduces water movement around the plant and enhance sediment deposition (Saenger & Siddiqi, in press; Bird, 1971; & Stephens, 1962); for example, tidal currents entering a *Rhizophora*-dominated forest can be reduced from 40 cm sec^{-1} to zero within 1m of entering the root network (Scoffin, 1970). Even a sparse vegetation cover can cause a substantial reduction in current velocity, and thus a reduction in the competence of the current to transport sediment (Fonseca, 1989).

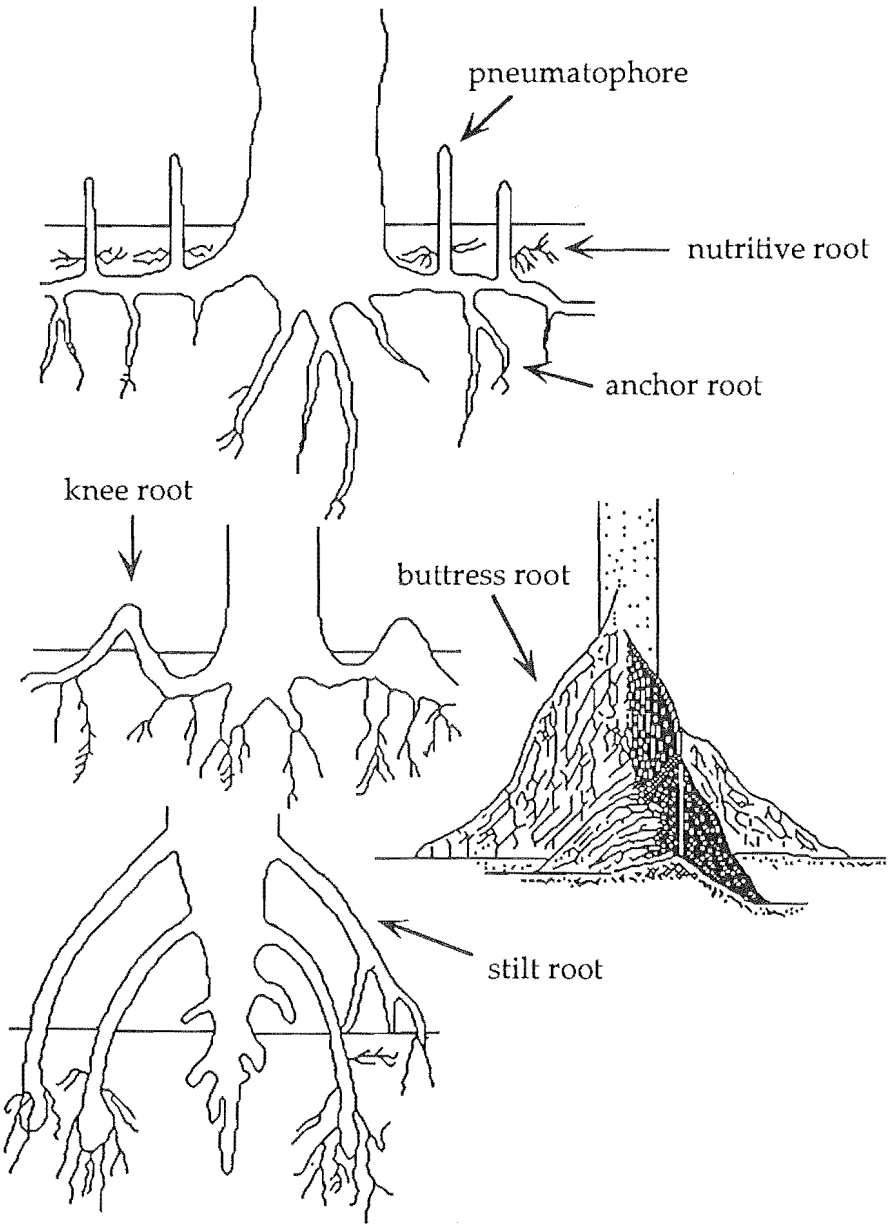


Figure 42 Major morphological root types found in mangroves (After Hutchings & Saenger, 1987).

The effective absence of currents within mangrove forests promotes deposition of clay and silt particles that would otherwise be held in suspension by the moving water; by reducing current velocities, the roots also limit the erosive effects of currents during storm events. The effectiveness of this dampening of tidal currents and storm waves by mangroves was demonstrated

in Bangladesh in 1990 when a storm moved 2 ton steel-reinforced blocks of a sea wall up to 100 m inland, while the mangrove forest about 0.5 km away suffered less than 1% damage (McConchie & Saenger, 1991).

Chemical role of mangroves

The mangrove environment is characterised by the presence of high salinity water, and mangroves have developed a number of mechanisms by which to survive in a high salt environment. Jennings (1968) reviews these mechanisms, which are: 1) uptake of saline water and; secretion of the salt; uptake of water while excluding the entry of the salt; development of a tolerance to the high salt levels and accumulation of the salt in tissues. Some species of mangrove emphasise one mechanism, others another (Hutchings & Saenger, 1987).

Pyrite is thought to form in mangrove soils within the boundary zone between the upper more oxidised sediments and the lower more strongly reduced horizons. In this zone, H_2S formed below will react with ferric compounds deposited above (Wada & Seisuwan, 1986). Transport of the metals to the upper, oxidised region will be primarily by bisulphide complexes (Lu & Chen, 1977; Salomons, 1985; and Salomons *et al.*, 1987). Pyrite in this environment forms microcrystalline spherical or framboidal clusters. and although some may be contained in organic debris, the majority is free of the organic matter (Rickard, 1973; van Dam & Pons, 1973).

Upper horizons of mangrove soils have highly variable redox characteristics, which result in a mottled appearance and rapid changes in Eh over short distances. Tunnels of burrowing animals and young active roots of the trees supply oxygen to the upper horizons and oxidise their surroundings whereas organic debris, especially debris from fine roots, causes localised highly reduced zones (Wada & Seisuwan, 1986).

Soil aeration is directly related to soil drainage and is therefore highly variable in mangrove forests; it depends on elevation, relief, and the physical characteristics of the substrate, particularly texture, but because mangroves promote the accumulation of clays, drainage in mangrove forests is usually poor and aeration is localised around roots and burrows. Low rates of infiltration can compound already adverse soil conditions, as shown by Clarke and Hannon (1967) for salt marsh soils in Sydney. In addition, because many mangrove soils are nearly saturated most of the time, spaces in the soil are water-filled and penetration of oxygen, an essential requirement for active root development, is reduced (Hutchings & Saenger, 1987).

Aerial roots of *Rhizophora* undergo several changes as they penetrate the sediment surface including an increase in gas spaces (acrenchyma) from 5 to 50%; these gas spaces may serve as an oxygen reservoir or as a system that allows a maximum root surface area per quantity of living tissue. These gas-filled roots leak oxygen into the surrounding sediment causing localised increases in Eh. Radial oxygen loss, enzymatic oxidation within and at the root surface, and microorganism-dependent oxidations near plant roots in waterlogged soils all help exclude soil-borne metals and other toxins (Armstrong, 1978; Armstrong; 1982; and Gleason & Zieman 1981). Radial oxygen loss from the roots results in the formation of an oxygenated zone in 1-2 mm wide zone between the root and the surrounding soil (rhizosphere), which then forms a buffer between the cells of the root and the hostile soil environment; iron oxyhydroxides (e.g., goethite or lepidocrocite; Armstrong, 1982) are commonly deposited in this oxygenated buffer zone.

Accumulation of metals

Factors affecting metal absorption by plants are those controlling 4 steps: (1) concentration and speciation of the metal in the surrounding soil; (2) movement of the metal from the soil to the root surface; (3) transport of the metal

from the root surface into the root; and (4) translocation of the metal through the plant (Fig. 43; Alloway, 1990). In mangroves, the same adaptations that act to exclude salt will act to exclude metal at steps 2 and 3 depending on the species. Metals will also be lost at step 4 by species (e.g., *Avicennia marina*) that actively excrete salt from their leaves (metals are carried out as chloride complexes). Uptake of mobile metals by plants largely depends on the total quantity of metal available, whereas in the case of strongly adsorbed metals, adsorption is more dependent on the amount of root produced. Roots possess a high cation exchange capacity (CEC), due largely to the presence of carboxyl groups, and each exchange assists movement of ions through the outer part of the root to the plasmalemma where active absorption occurs. Adsorption mechanisms vary for different metals, but ions which are adsorbed by the same mechanism will compete with each other (e.g., Zn absorption is inhibited by Cu and H^+, but not by Mn or Fe; Cu is inhibited by Zn, NH_4^+, Ca and K; Alloway, 1990).

The rhizosphere receives appreciable amounts of organic material from the roots, including exudates, mucilage, sloughed-off cells and their lysates. These organic compounds give rise to intense microbiological and biochemical activity, which enables plants to mobilise metals which are strongly adsorbed in the soil (Alloway, 1990).

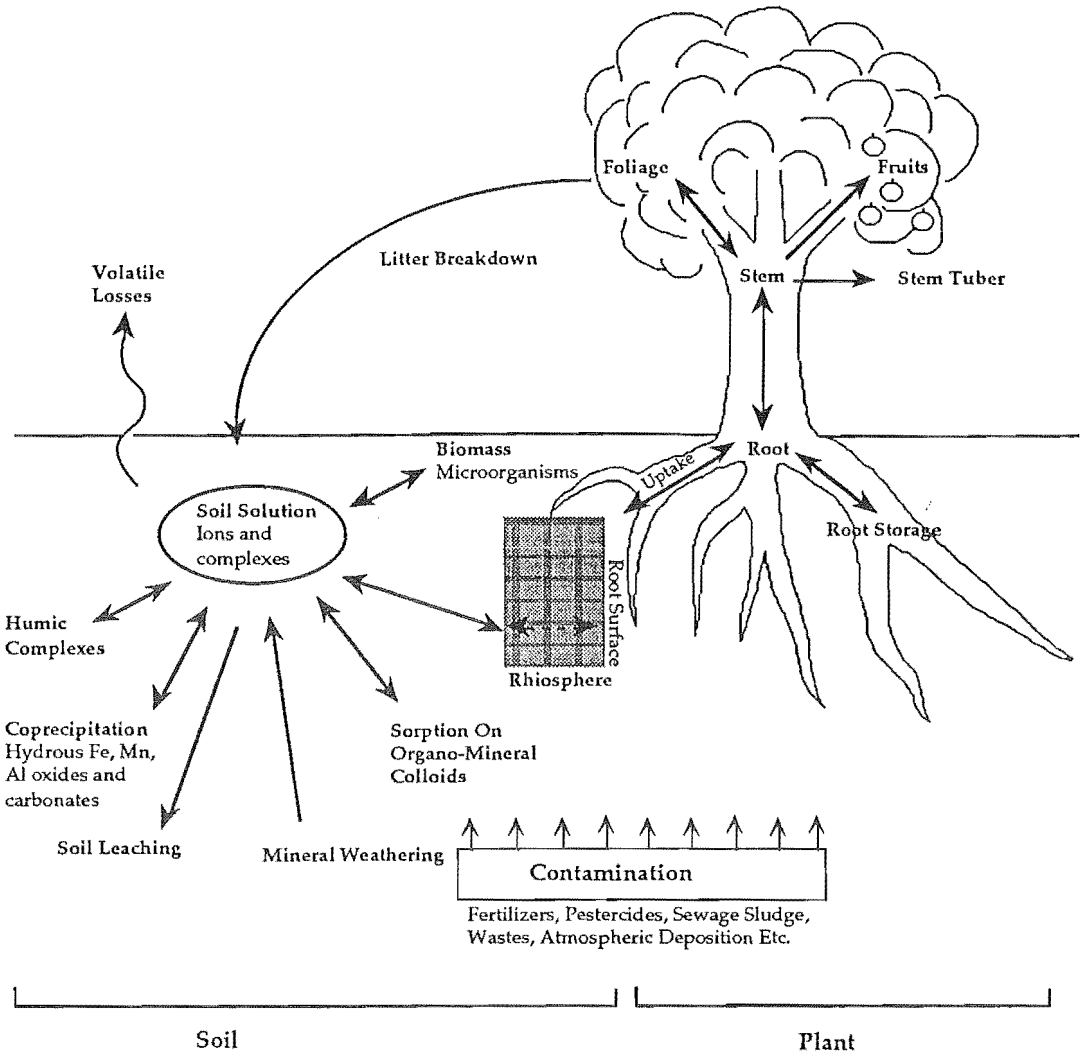


Figure 43 Schematic representation of the plant, soil metal relationships (After Alloway, 1990).

Role of algae and micro-organisms

Algae and the micro-organisms that are present in many environments are actively involved in the cycling of metals. Mercury is the most well known metal to be transformed by microbial activity. Because mercury-organic complexes have very high stability constants, once mercuric ions are complexed, exchange of mercury back into the water column is extremely slow and generally requires biological mediation. Formation of methylated mercury compounds by microbial mediation, the aquatic chemistry of mercury in the presence of chloride ions and the sulphate/sulphide system, and the tendency of

mercury to be adsorbed on suspended solids are reviewed by Gavis and Furguson (1972) and Summers and Silver (1978). Cadmium, lead and tin also form volatile methyl complexes similar to those of mercury and are produced by the same variety of bacteria (*Pseudomonas*) that is responsible for the methylation of mercury. Methylation subsequently raises the toxicity of all metals several fold (Summers & Silver, 1978).

Bacteria have also been shown to be involved in the cycling of nickel (Wood, 1987). In sediments, nickel forms stable and insoluble complexes with sulphide and thiolates to give nickel sulphides, as well as stable complexes with organic compounds which contain thiol groups. However, at the sediment water interface nickel forms weaker coordination complexes with oxygen donors such as carboxylate, hydroxyl, and other oxy-ligands (e.g., humic and fulvic acids, clays, metal oxides, etc.). Nickel does form stronger bonds with the oxygen donors associated with the cell surfaces of bacteria and algae, but these complexes are sufficiently unstable that nickel can exchange rapidly with Ca^{2+} or Mg^{2+} in the water. Several other metals that experience this type of exchange are Fe^{3+}, Zn^{2+}, and Cu^{2+} (Wood, 1987).

Sulphate-reducing bacteria such as *Desulphiovibrio desulphuricans* utilise simple organic molecules and the products of organic oxidation as an energy source (Jørgensen, 1982) and produce an abundance of potentially metal binding sulphide as a by product of their metabolic activity. The high sulphide ion activity associated with sulphate reducing bacteria also depresses the Eh in their environment and can thus have a major affect on metal mobility. The overall process of sulphate reduction is represented by the simple reaction:

$$2CH_2O + SO_4^{2-} \longrightarrow H_2S + 2HCO_3^-$$

where sedimentary organic matter is represented by the idealised formulae CH_2O.

Zueberer and Silver (1978), found that most nitrogen fixation in mangal

sediments was carried out by photosynthetic bacteria followed by the cyano-bacteria (blue green algae). Establishment of nitrogen-fixing bacteria around roots may be a critical factor in mangrove establishment, because during the early stages of development trapped, detritus is minimal and the sediment is nitrogen deficient. Ammonification, where organic nitrogen is converted by proteolytic bacteria and fungi to ammonia, may also occur in mangal sediments. The production of ammonia (NH_3) raises pH by its interaction with water to form ammonium (NH_4^+), which may then act as an energy source for nitrifying bacteria (Hutchings & Saenger, 1987).

Algae not only indirectly influence the dissolved metal concentration by raising pH and precipitating insoluble hydroxides, but also by direct uptake of metals from the solution. This accumulation may either be passive (adsorption on the outside of the cell) or active (incorporation in the cell tissue). Algae are responsible for about 4-14 % of metal removal (especially Cu) from the sediments of Ijsselmeer, Netherlands (Salomons & Mook, 1980).

Algae may also play a role in the binding and trapping of sediments. Sediment adheres to the sticky algal filaments even under quite strong currents. Where algae form mats, a smooth continuous surface is often produced; these mats protect the sediment surface from erosion and may withstand current velocities up to 100 cm sec^{-1}. However, where an edge of the mat is exposed the mat will quickly break-up under high current flow as the current undermines this edge (Scoffin, 1970).

Sediment/Fauna Interactions

Sediments are often considered as the ultimate sink for contaminants, be they chlorinated hydrocarbons, metals, radionuclides or nutrients. They are deposited in sediments and may persist long after the original sources of contamination are eliminated. A number of biologically-mediated processes could affect the cycling of these contaminants through the benthic ecosystem

including bioaccumulation, trophic transfer, migration, biodegradation, biodeposition, and bioturbation (Reynoldson, 1987).

A major process in mangrove forests involves sediment turnover by burrowing fauna. One of the best examples of bioturbation is reworking of mangal sediments by mud lobsters (*Thalasia anomala*), which produce mounds of excavated sediment up to 75 cm high above U shaped tubes that can extend up to 1.5 m below surface (Macnae, 1966; and Bennett, 1968). Large amounts of sediment rich in organic and sulphidic material are brought to the surface by such activity (Andriesse *et al.*, 1973). This sulphidic material then oxidises with the subsequent production of sulphuric acid (H_2SO_4) and may cause localised acid leaching of the sediment. Numerous burrowers at the Wynnum site also must be responsible for a significant turnover of sediment. The burrows also allow aeration of the sediment and subsurface waters, enhancing mangrove growth, increasing infiltration of surface waters, facilitating subsurface flow of water and causing some subsurface sulphide oxidation(Hutchings & Saenger, 1987).

Influence on Eh/pH conditions

Increased Cd, Cu and Ni concentrations in the oxidised sediments overlying reduced H_2S -bearing sediments has been attributed to removal of sulphide from the pore water as a result of biologically-mediated ventilation of the upper sediment. Such biological activity significantly enhances metal fluxes to waters (Emerson *et al.*, 1984) and tidal flats may act as significant sources for heavy metals (Morris *et al.*, 1982). Aller (1978) noted that the construction and irrigation of permanent tube-dwellings by sedentary infauna results in complex patterns of chemical reactions and diffusion gradients in sedimentary deposits. These complex patterns are reflected in the three-dimensional distribution of pore water constituents, diagenetically-mobile solid phases, biogeochemically-important microorganisms, and meiobenthos (Aller, 1978).

In addition to the above effects, bioturbation of the sediment tends to keep the system open with respect to sulphate, i.e. fresh sulphates can infiltrate the sediment and are then available for bacterial reduction. Whether the system was closed or open for the accumulation of sulphides can be shown by the measurement of stable sulphur isotopes in the resulting pyrites (Bloch & Krouse, 1992).

Physical Controls on Metal Accumulation

Physical controls an the accumulation of metallic ions in sediments involve the affects and interaction of grain size, mineralogy, evaporation, groundwater and tidal inundation.

Role of grainsize

Jenne (1977), in his review of clays as a mechanical substrate for the accumulation of trace metals, considered that precipitation of other geochemical metal sinks are important in the accumulation of metallic species. These sinks include the carbonates, phosphates, and both oxides and sulphides of iron and manganese. Förstner and Salomons (1980) recommended that the < 63 μm sediment fraction be analysed because this is where most metals occur because the finest grainsize fractions have high charge to mass ratios and high surface area to volume ratios and therefore have a large capacity to bind metals than do the coarse sedimentary fraction. At the Wynnum site the < 63 μm fraction commonly accounts for 80% of the total sediment (Fig. 41).

Role of mineralogy

Mineralogy of the sediment has an important control on the adsorption of metallic ions. Sandy soils with a high concentration of quartz and feldspars have a low capacity to accumulate metals (Förstner & Wittman, 1981; Salomons & Förstner, 1984; and Förstner, 1989), whereas clay minerals have a high to

accumulate metals by adsorption into interlayer sites as a result of ion exchange Minerals such as the aluminium and iron oxyhydroxides also have a high capacity to adsorb metal ions and will be discussed in the chemical controls section.

The net negative charge on clays arises from the isomorphic substitution of trivalent cations for silicon in the tetrahedral silicon layer (mostly trivalent aluminium, Follett, 1965; and Grim, 1968). Sometimes such substitutions are balanced by other lattice changes, for example, OH for O, or by filling more than two-thirds of the possible octahedral positions.

Clays may act in the mediation of metals in two distinct ways. They may either act directly to bind metals through their cation exchange capacity (CEC), or as a mechanical substrate onto which other sedimentary metal sinks may precipitate. (Fig. 44, Jenne, 1977). Processes of metal adsorption onto clays are similar to those onto iron or aluminium oxide surface coatings. In addition to the cation exchange sites, many metals may establish covalent bonds to functional groups on grain surfaces (Ellis & Knezek, 1972).

Because of the electrostatic attraction of metals to clay minerals, anion behaviour of the clay can be described in terms of Lewis acid-base properties. The degree of "softness" or "hardness" (degree of surface charge to unit area) of the clay depends on the degree of isomorphic substitution that has occurred within the lattice (Puls & Bohn, 1988).

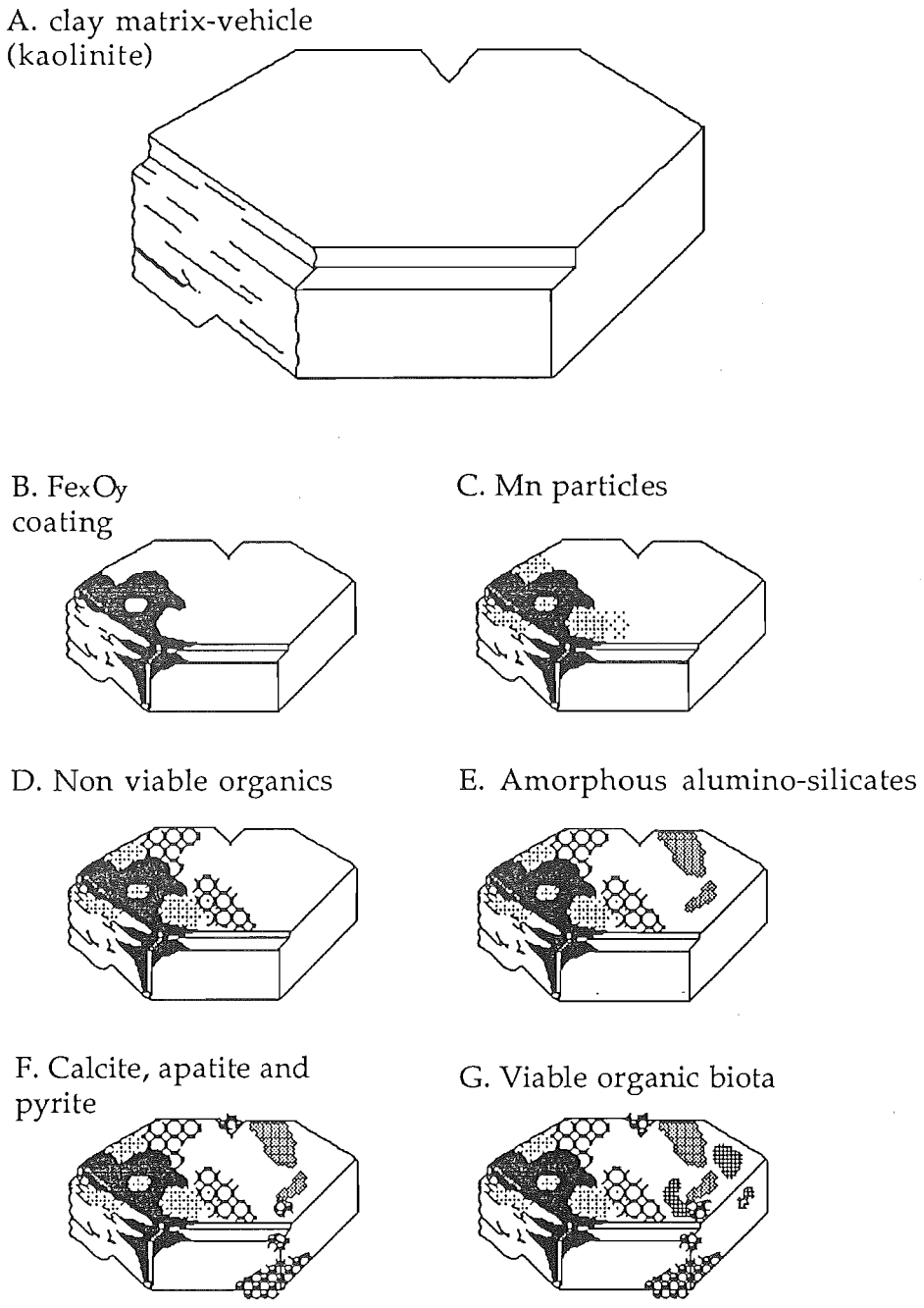


Figure 44. Schematic representation of the important trace-element sinks on the surface of an idealised kaolinite crystal (After Jenne, 1977).

An idealised kaolinite has a net negative charge on clean planar surfaces and a net positive charge on clean edges onto which other sinks may precipitate (Fig. 44; Jenne 1977). Follett (1965), considers that substitution of Mg^{2+} for Al^{3+}

into the octahedral aluminium layer is less likely in kaolinite, but such substitution is a major source of charge in montmorillonite, (McBride,*et al.* 1975). To obtain a cation exchange capacity of 2 meq/100g for kaolinite only about 1 in every 400 silicons need be replaced by aluminium (Schofield & Samson, 1953).

Anionic exchange sites may develop on the clay edges where due to structural discontinuities edges are incomplete and thus expose multivalent structural cations (Si^{4+} and Al^{3+}). Exposed cations are then partially or wholly screened by hydroxyl and/or other anions, which may in turn be susceptible to exchange by other anionic solutes e.g. organic material (Follett, 1965; Grim, 1968).

The structural source of the charge deficiency in montmorillonite (i.e., the octahedral or the surficial tetrahedral layer) may also affect the chemical properties surface. The number of cationic or anionic exchange sites on the clay also depends on the pH of the system: as pH rises, the number of cationic exchange sites increases and the number of anionic exchange sites decreases. There is also an apparent increase in the CEC, depending on the amount of hydrolysis of the exchanging ion. The hydroxyl complexes (e.g., $CuOH^{+}$, $FeOH^{2+}$, $HgOH^{+}$) tend to be softer than the uncomplexed cation i.e., Cu^{2+}, Fe^{3+}, or Hg^{2+} and will bind more readily with soft clay anions (Jenne, 1977; Puls & Bohn, 1988). Similarly, adsorption of cations will depend on the degree of softness and hardness of the anionic clay. The binding preference of various clay minerals is shown in **Table** (8). Puls & Bohn (1988) showed that cadmium is preferentially bound relative to zinc on kaolinite (**Table** 8), but for montmorillonite both metals bind equally. The greater degree of isomorphic substitution in montmorillonite, gives it a higher cation exchange capacity (CEC), but makes it a harder Lewis base than kaolinite and hence its ability to bind cadmium, a soft Lewis acid, is reduced.

Table 8 The selectivity of soil constituent for divalent metal ions (modified after Alloway, 1990).

Adsorbent	Selectivity	Reference
Montmorillonite (Na)	Ca > Pb > Cu > Mg > Cd > Zn	Bittel & Miller, 1974
	Cd = Zn > Ni	Puls & Bohn, 1988
Illite (Na)	Pb > Cu > Zn > Ca > Cd > Mg	Bittel & Miller, 1974
Kaolinite (Na)	Pb > Ca > Cu > Mg > Zn > Cd	Bittel & Miller, 1974
	Cd > Zn > Ni	Puls & Bohn, 1988
Smectite, Vermiculite &	Zn > Mn > Cd > Hg	Stuanes, 1976
Kaolinite	Zn > Cd > Mn > Hg	Stuanes, 1976
Albite, Labradorite	Pb > Cu > Zn > Ni> Cd > Co > Sr > Mg	Kinniburgh *et al.*, 1976
ferrihydrite	Pb > Cu > Zn > Co > Ni	Mackenzie, 1980
Fe hydrous oxides hematite	Cu > Pb > Zn > Co > Cd	Forbes *et al.*, 1976
goethite	Pb > Cu > Zn > Cd > Ca	Harmsen, 1977
Mineral soil on marine clay	Pb > Cu > Cd = Zn > Ca	Bunzel *et al.*, 1976

Electrostatically-adsorbed divalent and trivalent cations also hold clay particles together by acting as bridging ion (Piccolo & Mbagwu, 1989). These binding ions effectively flocculate the clay and increase the grain size distribution. Flocculated clay are more resistant to transport and at the interface of nonmarine and marine waters, where monovalent ions are replace primarily by divalent calcium and magnesium, flocculation is a major cause of clay sedimentation (Grim, 1968; and Weaver, 1989).

The vertical distribution of metals at the Wynnum site appears to be strongly influenced by the distribution of clay minerals. The lower portion of each core comprises fine to very fine sand with a much lower metal concentration than in the overlying kaolinite clay-rich sediment. Cores MCC 012 and MCC 010 show that metal concentration increases where clays are present. The top of the weathered basalt is mostly kaolinite clay, with some smectite and other accessory minerals. These clays strongly adsorb metals that migrate across them in the groundwater.

Core MCC 011 does not show this increase in metals at the top of the basalt. There are two possible reasons for this: firstly, the mineralogy in this core is mostly quartz and kaolinite, with minor accessory minerals, whereas the other

two cores contain some smectite clay and secondly, the groundwater leachate flow around this area due to a local structural high. The sequential data for the cores show that about 10 % of the available Pb^{2+} is bound to the exchangeable phase. For some samples this rises to 20 - 25 % (e.g., MCC 003/2) but this is uncommon. Pb^{2+} and the other soft Lewis cations show decay curves down through the cores, indicating that the surface increase in clay content absorbs Pb^{2+} in preference to other metals (Alloway, 1990). Because kaolinite is a softer Lewis base, the adsorption of Pb^{2+} onto this sediment is expected (Brown, 1955; and Puls & Bohn, 1988).

For the lower sections of cores MCC 012 and 010, the exchangeable metal value is about 25 % of the total metal present. Throughout the sequential extraction procedure, organic matter was extracted progressively and hence organic matter bound metals cannot be accessed separately. Progressive extraction of organic matter has a significant affect on the concentration of metals in the other phases because it provides a major sinks for metallic species (Jenne, 1977; Inoue *et al.*, 1990; and Raspor, 1989). Because organic matter is strongly attracted to differentially-charged particles, clays not directly acting as the site for metal adsorption nevertheless probably play a major role by acting as a site for the adsorption of organic matter and iron oxides.

Figure (41) shows that clay and silt fractions dominate within the trees and the salt marsh. These data also show that at the coast there is a sharp increase in the proportion of the sand fraction. Once the transect passes out of the mangal area onto the mud flats, there is a fall in the concentration of metals, which is inferred to be a direct result of the decrease in metal-binding clays.

Role of evaporation and salinity in metal accumulation

Evaporation of tidal waters initially leads to an increase in the ionic strength of the soil pore waters and ultimately may result in the deposition of new sedimentary minerals (e.g., gypsum and halite). Evaporation will also dry

the sediment causing changes in the redox condition, and thus the speciation of metals present.

For the sediments taken from the Wynnum site, very little gypsum or other sulphate-containing minerals were found, but in all samples large amounts of halite were present. The precipitation of gypsum precedes the precipitation of halite from sea water and it is likely that the absence of gypsum from the sediment is due to the continual removal of sulphate as sulphide by sulphate reducing bacteria. Continual removal and replenishment of sulphate in the Wynnum sediments would strongly indicate that the system is open (Bloch & Krouse, 1992).

The role of salinity in heavy metal cycling is ignored by some authors, but increases in salinity have been shown to mobilise cadmium from estuarine sediments (Salomons & Förstner 1984). Metals released from anoxic sediments by oxidation are also mobilised through complexing with chloride ions or ligands released from decomposing organic matter (Salomons & Mook, 1980).

When the ionic strength of the pore water rises, the large quantities of chloride and sulphate present have a major affects on the adsorption of metallic species by clays and organic matter. Increased chloride concentration due to evaporation sets up competitive complexing reactions for metallic ions, and many metallic species form soluble complexes with chloride e.g., Cu, Ag, Hg, Fe, Pb, Co and Cd (Fritz & Schenk, 1979; and Aylward & Findlay, 1989). For cadmium, which forms soluble chloride complexes, exposure to 1000 ppm Cl^- reduces cadmium adsorption by as much as 20 % (Salomons & Mook, 1982; and Förstner, 1989). Conversely, Zn adsorption shows the reverse trend to that of cadmium and as chloride concentration increases the adsorption of Zn by kaolinite and montmorillonite increases because few Zn-Cl complexes form in solution (Stanley & Byrne, 1990). Increases in sulphate concentration reduces Ni adsorption because sulphate competes with the clay surface to form $[NiSO_4]^0$ (Puls & Bohn, 1988).

Role of groundwater

Transport of metals and organic leachates via groundwater depends on the hydraulic factors governing water movement and on chemical interactions between the sediment and water. Contaminated ground water tends to flow as a relatively undiluted plug or plume along with the ground water in the aquifer (Manahan, 1990).

The degree of attenuation of the contaminant depends on the characteristics of the substrate through which fluid is passing and on the chemical conditions within that substrate. The presence of colloidal material in the groundwater will significantly enhance contaminant transport; when colloids are stable (i.e., do not aggregate easily or adhere to surfaces), they may be expected to travel long distances. When they are unstable (i.e., when they aggregate rapidly or attach), they can be expected to deposit in porous media and to reduce aquifer permeability. Where humic and other organic macromolecules are present, it is expected that ground-water transport will be enhanced because of the natural surfactant nature of these molecules (O'Melia, 1989). Unfortunately, the determination of colloids in groundwater is next to impossible because the digging of a hole to obtain a sample will change the chemical characteristics of the groundwater and alter the character of the colloids present (McCarthy & Zachera, 1989).

At Wynnum, groundwater plays a major role in the distribution of metallic species (**Fig.** 45). The presence of elevated metal concentrations in the lower portions of cores shows that there is a subsurface flow of metallic ions. The analysis of the groundwaters and samples from the leachate drain reveals low dissolved metal loads (in the 10's of ppb), but even a low concentration can result in a large total if these ions are deposited over a long period of time.

The piesometric head across the field area is from the tip to the coast. This piesometric head is less during the high tide period than during the low tide period, but the flow of groundwater is always from the tip toward the coast; the

groundwater flow volumes are unknown.

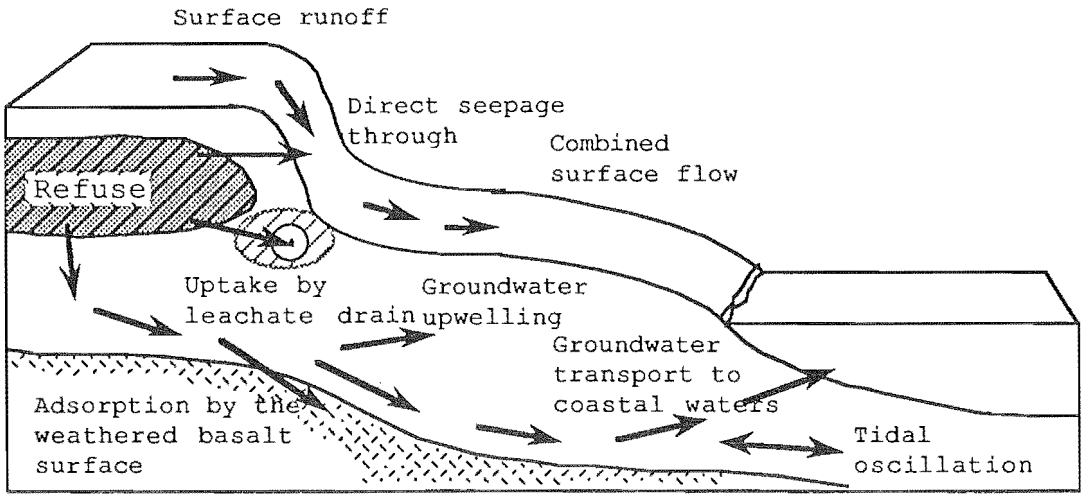


Figure 45 Schematic diagram of the flow paths of leachate, surface water and ground water from the Wynnum Tip. The weathered basalt not only controls the ground water flow but also plays a major role in the removal of metallic species.

Tidal influences

Tidal influences at the Wynnum site include both physical and chemical effects. Inundation of sediments and soils reduces availability of some metals for plant uptake and increases the availability of others. Cu and Zn show marked decrease in availability due to the increase in soil pH, caused by tidal flooding, and the associated precipitation of metal hydroxides, carbonates and sulphides (Beckswith *et al.*, 1975; and Dutta *et al.*, 1989).

The fresh influx of tidal water also brings a fresh influx of fine sediments, plus sulphate and chloride ions. Fresh sulphate allows the continued accumulation of sulphides by sulphate reduction and thus keeps the system open. Irregular flushing of the sediment by tides allows sediments to dry and evaporate remaining salt water, increasing soil salinity and ionic strength.

Tidal inundation brings with it a decrease in the piesometric head across the field area and a slowing in groundwater flow. The effect of the incoming tidal water forces ground water to backup against the tidal wedge and raises the

groundwater levels. Raising the groundwater may cause an increase in mixing of tip leachate, thereby diluting the leachate. In contrast the falling tide is drawing out the more saline leachate waters from the tip, as reflected in the salinity profile for piesometer 1. Piesometer 1 shows a continual increase in salinity throughout the tidal cycle an initial increase in salinity due to the influx and mixing of coastal waters and a second increase in salinity is due to the drawing out of the saline tip leachate (see **Fig.** 39).

Chemical Controls on Metal Accumulation

Chemical processes operating in sediments are probably the most important controls on accumulation and mobilisation of metals but many physical factors such as bioturbation exert major influences on the chemical conditions.

Role of oxides

Metal oxides in the aqueous environment are generally covered with hydroxyl groups, making them capable of cation exchange; several authors have calculated the adsorption potentials for both aluminium and iron oxides (e.g., Quirk & Posner, 1975; Kinninburgh *et al.*, 1976; and Schindler, 1985).

Kinniburgh *et al.* (1976), reported that the adsorption of heavy metals onto iron oxides depended strongly on pH, and found the following relationships: Pb (3.1) > Cu (4.4) > Zn (5.4) >Ni (5.6) > Cd (5.8) > Co (6.0) > Sr (7.4) > Mg (7.8) (numbers inside the brackets are the pHs at which half the possible sites for the oxide gel are filled by the metal). For the aluminium oxides, the order was Cu (4.8) > Pb(5.2) > Zn (5.6) > Ni (6.3) > Co (6.5) > Cd (6.5) > Mg (8.1) > Sr (9.2). The high ability of iron oxide to adsorb the large Pb cation is thought to be due to the relative openness of the iron oxide structure compared to that of aluminium oxide (Kinniburgh *et al.*, 1976).

Because there is oxygen loss from the mangrove roots under anaerobic

conditions and the formation of oxyhydroxide material around leaking roots (Armstrong, 1978; Armstrong; 1982; Gleason & Zieman 1981; and Wada & Seisuwan, 1986), oxides probably play an important role in the cycling of heavy metals at the Wynnum site. The sequential analysis data indicate that the surficial sediments do contain appreciable quantities of oxide-bound metal (**Appendix** 2), although the extraction of organic matter with the dithionite shows that some of the contribution to the oxide phase is due to organic matter. The extraction of lead from the section of Transect 4 (closest to the tip, **Fig.** 33) by dithionite is in keeping with the literature that suggests Pb is adsorbed by iron oxides even at low pH and is not readily desorbed (Kinniburgh *et al.*, 1976).

The sequential data from elsewhere in the Wynnum area show that oxides account for about 20 % (and in some samples 80%) of the available metal. Samples with a high percentage of oxide-bound metals are always from the lower redoxcline, where the excretion of oxygen by mangroves raises Eh, or at the very surface of the sedimentary pile (see later **Fig.** 49).

Role of sulphides.

Metal sulphides play a major role in the immobilisation of metals in the environment as a result of the low solubility of metal sulphides compared with their respective oxide, carbonate and phosphate compounds.

Iron sulphides have also been shown to accumulate non-ferrous metals in polluted sediments (e.g., Luther, 1980; Förstner & Wittman, 1981; and Förstner, 1989) may incorporate significant quantities of metals such as Mn, even though the other metals are capable of forming their own sulphides. However, some metals such as Cd and Hg tend not to be incorporated in iron sulphides. In some studies it has been found that when Zn concentrations exceed 1000 ppm, a discrete ZnS is formed, which may contain trace amounts of Ni and up to 25 % iron (Luther *et al.*, 1980); lead should also have formed a free sulphide, but it was

not observed, probably because of lead absorption by clay minerals . Clearly, the coprecipitation of metals with the more abundant iron sulphides provides the dominant, metal sulphide precipitation mechanism and it is only when concentrations of contaminant metals cross a threshold level that precipitation of discrete metal sulphides occurs (e.g., Zn concentrations of about 1000 ppm are required for the precipitation of ZnS).

At Wynnum sulphides play a major role in the immobilisation of metallic species. From the sequential data (**Appendix** 2), about a third of the total metal was extractable by the aquaregia, though this value often fell to below a quarter for samples from the redoxclines (about 30 cm depth and at the surface). There are also several sites in the area where re-accumulation of the metals is occurring (e.g., the more seaward parts of Transect 1, 2 and 4) due to an increase in sulphide concentration, increase in pH, and decrease in Eh.

Sulphide ions compete with dissolved organic matter (DOM) in the sequestering of Cu, Zn, & Cd from the environment often to the extent that DOM does not complex with the metals (Pauli, 1975; and Salomons *et al.*, 1987). The affinity of sulphide anions for metals is so great that Kester *et al.* (1983) recommended that where contaminated sediments cannot be successfully removed, a constant anoxic environment be maintained for the retention and control of pollutants. A summary of the positive and negative effects of anoxic conditions on the mobility of heavy metals, methyl mercury and organochlorine compounds is given in Table (9). Lu and Chen (1977) find that the migration of metals from the sediment to overlying waters under anaerobic conditions is largely controlled by sulphide complexes of Cd, Hg, & Pb.

Table 9 Summary of the positive and negative effects of anoxic sulphidic conditions in sludges (after Kersten, 1988).

Element or compound	Advantageous Effects	Disadvantageous Effects
Heavy Metals (e.g., cadmium)	Sulphide precipitation	Formation of mobile polysulphide and organic complexes under certain conditions with low $Fe(OH)_3$concentrations; strong increase increase mobility under acidic conditions.
Metalloids (e.g., Arsenic)	Capture by sulphides	Highly mobile under post-oxic & neutral/slightly alkaline conditions
Methyl Mercury	Degradation/ inhibition of $CH3Hg^+$ - formation by precipitation of HgS	Formation of mobile polysulphide complexes, especially at low Fe concentrations
Organochlorine compounds	Initiation of biodegradation by reductive dechlorination (methanic environment is more favourable)	Formation of harmful terminal residues with certain compounds especially in sulphidic environments; mobilisation through colloidal matter in pore waters

Role of carbonates

Detrital carbonates generally have a diluting effect on metal concentrations in sediments (Salomons & Förstner, 1984). However, the presence of authigenic carbonate minerals may result in the binding of metallic ions by coprecipitation. Because coprecipitation and adsorption are analogous processes (Ellis & Knezek, 1972; Quirk & Posner, 1975; and Jørgensen & Jensen, 1985), the processes will be considered as one here.

Carbonates may form wherever organic matter is being microbially broken down, either aerobically or anaerobically. In anaerobic marine environments, sulphate reduction occurs in conjunction with the oxidation of the organic matter where:

$$2CH_2O + SO_4^{2-} \longrightarrow H_2S + 2HCO_3^-$$

$$HCO_3^- + Ca^{++} \longrightarrow CaCO_3 + H^+ \text{ (simply)}$$

or $15CH_2O + 8CaSO_4 + 2Fe_2O_3 + 7MgSIO_3 \longrightarrow 4FeS_2 + 8CaCO_3 + 7MgCO_3 + 7SiO_2 + 15H_2O$ (more fully; from Berner, 1984)

It can be seen from the above equations that the simultaneous production of sulphides and carbonates can occur in anaerobic environments, but the production of free sulphide precludes the precipitation of siderite ($FeCO_3$) because Fe preferentially combines with S^{-2}; this preference for sulphide can be seen in the sequential analysis data (**Appendix 2**) where very little iron is released by the $BaCl_2$ and acetate phases (Berner, 1984; and Dutta *et al.*, 1989).

Lead can be strongly affected by coprecipitation with carbonate minerals to give cerrusite ($PbCO_3$) and it is common in high Mg calcites. In coprecipitation with calcite, the activity of Pb is reduced more than if a discrete cerrusite phase precipitated; in a coprecipitate with $CaCO_3$, the activity of $PbCO_3$ will be less than 1 and should decrease roughly in proportion to its mole fraction in the mixture. The reduction in activity implies a parallel reduction in lead solubility, mobility, and bioavailability (Sposito & Page, 1985). Within the sediments at Wynnum the carbonate phase accounts for between 10 and 20 % of available lead. The higher values are from the surficial sediments where more carbonate is produced (**Appendix 2**, see later **Fig. 49**). Overall it would seem that lead in the Wynnum sediments is preferentially adsorbed by clays and the production of cerrusite is minor.

Cadmium is also affected by the presence of carbonate minerals. Ionic cadmium replacement of calcium can take place on the surface layer of carbonate minerals when through a solid solution process and only when all of the calcite surface has reacted will free $CdCO_3$ precipitate (Papadopoulos & Rowell, 1988; and Alloway, 1990).

The acetate-extractable carbonate phase in the Wynnum area is insignificant in the mobilisation of iron (< 100 ppm or 0.01% iron was mobilised); indicating that sulphide preferentially sequesters iron. Data for the carbonate phase will be affected by the significant amounts of organic matter extracted by the acetate. However, the acetate-extractable (carbonate) phase is important in

the accumulation of other metals at Wynnum, especially in the surficial sediments. Acetate-extractable metal is at a maximum in the 10 to 15 cm depths in the cores and from the grab samples taken at the surface. This depth in the cores corresponds with the zone of maximum competitiveness for metals where carbonates, organics, oxides, sulphides and clays all have metal binding potential (see later Fig. 49). The acetate-extractable phase accounts for 10 -20 % of the bound metals at Wynnum, though this value depends on the metal involved (e.g., the mechanism is more important for Pb and Zn) and the sample's stratigraphic position (Appendix 2).

Role of organic matter

The ability of soil and sedimentary organic matter to form stable combinations with metal ions is well established. with a variety of compounds being involved, particularly humic and fulvic acids (Stevenson & Ardakani, 1972).

Humic and fulvic acids are the stable end products of microbial breakdown of organic particulate matter. Fulvic acids are the lower weight (<10,000 Daltons) acid-soluble fraction, whereas humic acids are the high weight (>10,000 Daltons) acid-insoluble but fraction. The structures of these compounds is not known, but they contain phenolic, amine, aliphatic and carboxylic groups that have a metal binding capacity (Raspor, 1989); the range of compound present depends on the environment of formation and on the type of parent material (Anderson *et al.*, 1990; and Malcolm, 1990). Present with the humic and fulvic acids are tannic acids, which have the capacity chelate metal ions (Branca *et al.*, 1990).

A number of authors (e.g., Cooper & Harris, 1974; Nissenbaum & Swaine, 1976; and Mackey & O'Sullivan, 1990), found that the most Cu, Mo and Zn were bound in humic substances. The organic fraction becomes less important for Ni, Co and Pb, and is insignificant for Mn, V, and Fe. For a salt marsh, 95 % of

metals in the sediments were associated with inorganic matter. The exception to this was Cd, where 12% of the total cadmium was extractable with the organic phases (Pellenbarg, 1981).

Humic and fulvic acids can bind metal ions through both electrostatic forces (attraction of a positively charged metal ion to an ionised COOH group) and by electron-pair sharing (formation of a covalent linkage). Many kinds of complexes are possible, and no single stability or formation constant can be used to describe the strength with which metals bind to humic substances (Stevenson & Ardakani, 1972). Jonasson (1977) established a probable order of the binding strength of metals onto fulvic acids of Hg > Cu > Pb > Zn > Ni > Co. However, the binding capacity for a metal varies with the pH of the soil solution; for example at pH 6 the binding order of humic material is Cd > Zn > Ni > Mn > Cu > Pb > Hg (Brümmer, 1986), whereas at pH 5.0 the binding order is Cu > Pb > Fe > Ni > Mn ≈ Co > Ca > Zn > Mg; at pH 3.5 the order is Cu > Fe > Ni > Pb > Co > Ca > Zn > Mn > Mg (Ellis & Knezek, 1972).

Pauli (1975) showed that where metal humates are in contact with hydrogen sulphide, the precipitation of the metal sulphide is likely to take place in preference to organic chelation. Under certain physiochemical conditions, elements like Cu, Zn, Cr and Cd can simultaneously form metal sulphides and metal-organic complexes; but this is not common (Hirner et al., 1990).

Humic-like substances in anaerobic seeps from landfill site are similar to organic substances found in soils, though these compounds have lower molecular weight, hence a higher mobility and it is believed that these organics represent an early stage in the development of humic acids (Weis *et al.*, 1989). The decay of organic matter follows the process of initial loss of metals associated with protein and carbohydrate loss, which has been linked to the process of humic precipitation via a "Millard Reaction" (Yamamoto & Ishiwatari, 1989) followed later by an increase in metal uptake as molecular size grows (Rice & Windom, 1982). The production of organic chelates within the tip

probably provides major transport mechanism for moving metals from the tip to the surrounding sediment. Although a high proportion of metals may be leached from the tip as chelates, conversion to sulphides and other chemical forms in the upper portions of the sediments within the mangrove forest and adjacent environments rapidly reduces the proportion of metals bound to organic compounds. However the stability of these organic chelates in groundwaters is unknown and their low weight and high mobility indicate that they may be important in the subsurface transport of metals.

Humic molecules are adsorbed on the surface of some clay minerals through polyvalent cation bridging, to form humus-clay complexes (Piccolo & Mbagwu, 1989) This adsorption not only binds the clay, but should also orient the hydrophobic components of humic molecules toward the outside of the clay aggregate, thereby preventing water infiltration. By this mechanism organic matter can effectively increase the binding capacity of clays. However, Piccolo and Mbagwu (1989) show that if humic matter reaches a threshold concentration then the flocculated clays will disperse, infill pore spaces, decrease infiltration and consequently raise Eh.

Data from Saenger, McConchie and Clark (1991; **Appendix** 5), shows that while levels of Cu and Zn are quite high in the organic litter Pb levels are low and tends to show that Cu and Zn have a preference for organic matter over lead. The export of organic matter-bound metals from Wynnum by the mechanism postulated by Boto and Bunt (1981) is likely to be insignificant because of the small tidal range, lack of deep tidal channels for out-flowing water to concentrate in and entrain large amounts of fine grained organic matter, and because there is an apparent migration of metals from the sewage outfall into the coastal strip of trees.

At the coast Transect 5 there is an increase in the mercury and zinc concentrations at a depth of 30 cm, which is also associated with an increase in sulphide. These metals are likely to be derived from the sewage outfall about 200

m north of the sample site and are most likely to have been transport with the incoming tide from the outfall as suspended organic matter (2.5 - 53 μm; Petronio *et al.*, 1989; and Yeoman *et al.*, 1989)., which has then settled to infiltrate the sandy sediments (Molenar, 1986).

Organic matter at the Wynnum site may play a minor role in the immobilisation of metals, because the high-weight organics compounds are generally immobile in the sedimentary environment (Hirner *et al.*, 1990). The higher weight organic molecules would not be mobilised, during sequential analysis until the aquaregia extraction, and as such are more likely to represent the organic sedimentary sink than are the more mobile lower-weight, fractions. Although, there is some correlation between the total organic carbon and the accumulation of metals at Wynnum, this accumulation is often accompanied by an increase in the sulphide content.

Because much of the lower weight organics were progressively extracted during sequential analysis it is therefore likely that low weight organic molecules play a role in metal mobilisation within the Wynnum sediments. For example for core MCC 002/03, nearly half of the total zinc is readily extractable and it likely that a large proportion of this zinc is bound to the readily-soluble, lower-weight organics as zinc has a preference for these types of organic molecules (Cooper & Harris, 1974); the slightly less soluble, and higher-weight organic fractions extracted by the acetate may also account for significant levels of zinc (Mirave & Orioli, 1989). However, although organic chelates are probably responsible for much of the metal transport within the Wynnum area they are unlikely to be responsible for long term immobilisation

Role of pH/Eh

The pH strongly affects the binding of metallic species onto organic matter because below a pH of 4.3, COO^- (carboxylate) groups become protonated leading not only to a size reduction in the humic molecule (John *et*

al., 1988; and Vasconcelos *et al.*, 1989), but also to the loss of metallic ions, which are then free for animal and plant uptake (Gjessing *et al.*, 1989).

The pH of sediment/water system plays an important role in the adsorption of metal ions because pH determines the isoelectric point of the absorbing solid. The isoelectric point is where the surface charge of colloidal material is 0; it marks the change in charge from negative to positive (Yariv & Cross, 1979). In seawater and associated sediments, where pH is near neutral to slightly alkaline, most colloidal material is negatively charged, but as the pH falls the isoelectric point is approached and may be passed (**Table** 10). Once the isoelectric point of the colloid is passed, metals associated with the colloid will be desorbed. This ability of colloidal material to change electrical charge and desorb metals has been shown to be significant in the contamination of oysters by cadmium (McConchie, 1987; McConchie & Lawrence, 1991).

Free hydronium ion plays only a minor role in the charge neutralisation of clay minerals in water; it is the other ions in solution such as K, Na, Mg and Ca that are primarily involved in this process. However, the extent of metal ion adsorption is greatly affected by pH because both the surface acidity and the hydrolysis of the metal ion increase abruptly at a specific pH value and then remain constant over a wide pH range. The pH value at which adsorption density increases is referred to as the pH of adsorption edge. This pH value has been correlated to the first hydrolysis constant (**Table** 11; Huang *et al.*, 1987) of the metal ion, and these pH values imply that MOH^+ species play a major role in metal-ion adsorption (Brümmer, 1986; and Huang *et al.*, 1987). In close agreement to the order of metal ion hydrolysis pH's is the order of relative mobility of the metal ions. In acidic soils the mobility of metals decreases in the order Cd> Zn> Ni> Mn> Cu> Pb> Hg (Brümmer, 1986).

Table 10 Isoelectric points for common colloidal materials (After McConchie, 1987).

Compound	IEP
Al(OH) 3 [amorphous]	7.1-9.4
α-Al(OH)$_3$ [gibbsite]	5.0
γ- Al2O$_3$	8.0 - 8.5
Fe(OH)$_3$ [amorphous]	7.1 - 8.5
α-FeOOH [goethite]	3.2 - 6.7
γ-FeOOH [lepidocrocite]	5.4 - 7.4
FeOOH [limonite]	3.6
α-Fe$_2$O$_3$ [hematite]	7.8
γ-Fe2O3 [maghemite]	6.7
MnO2	4.0 - 4.5
Mn(OH)2	7.0
SiO2 [quartz]	2.2
SiO2 [amorphous]	1.8
Sulphides	<6.0
CaCO3 [calcite]	9.5

The pH of the soil may also act in the condensation or mobilisation of polyvalent cation oxyhydroxides. Sparingly-soluble hydroxides and oxides can be precipitated from solution or remobilised from the soil by minor changes in pH (**Fig.** 46). Because oxyhydroxides (especially of Fe and Al) play an important role in the adsorption of heavy metals, the effects of changing pH can result in increased accumulation or release of metallic ions (Rosler & Lange, 1972; and Yariv & Cross, 1979).

Table 11 Dissociation constants for hydrated metals (After Aylward & Findlay, 1989).

Hydrated Metal ions	pK_a		pK_a
Aluminium (III) ion	4.85	Chromium (III) ion	3.95
Copper (II) ion	7.34	Iron (III) ion	2.17
Lead (II) ion	7.8	Manganese (II) ion	10.59
Nickel (II) ion	9.86	Zinc (II) ion	8.96

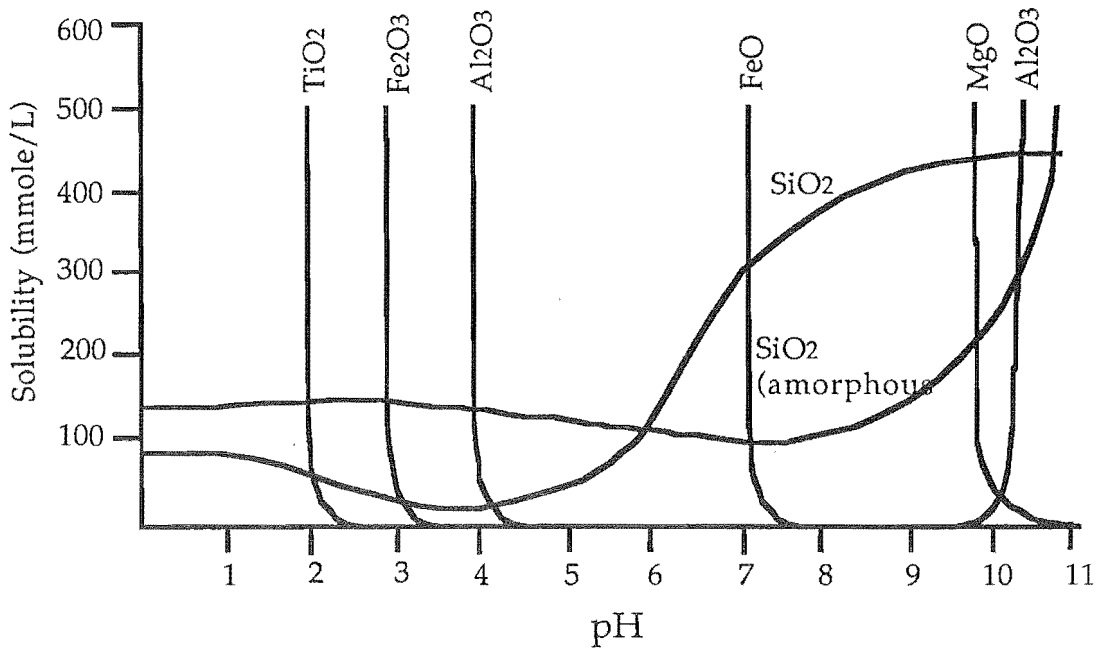


Figure 46 Variation in the solubility of some common oxides as a function of pH (After Rosler & Lange, 1972).

Redox is attributed as the prime control for accumulation of metals in most sediments. Cadmium and molybdenum naturally accumulate in the sediments of Ucluelet Inlet, British Columbia, where there is no anthropogenic input of these metals because of sulphide (derived from the overlying waters) precipitation at the redoxcline interface (Pederson *et al.*, 1989).

There are two ways that redox may affect metals in sediments and soils either directly through a change in the oxidation state of the metal itself, or indirectly through a change in oxidation state of a different ion contained in a ligand that can form complexes with the metal. Redox equilibria are governed by the negative common logarithm of the aqueous free-electron activity, the pE value. The pE values for soils lies in the range of -6.8 to +13.5. At pH 7.0 and a pE of 7.0 - 13.5, a soil would be oxidising; it would be moderately reducing if pE were 2.0 - 7.0, reducing if pE were -2.0 - 2.0, and highly reduced pE were -6.8 - 2.0. The measurement pE is not often possible because the concentration of all

oxidised and reduced species and the pH in the soil solution must be known. Hence, pE is generally measured in the field as an electrode potential (Eh) with an appropriate electrical cell (Sposito & Page, 1985).

In redox reactions, H^+ plays a strong role because the reactions are usually involve both proton and electron transfer reactions (Morgan, 1987). Redox reactions in soils are frequently slow reactions, in part because reduction and oxidation half-reactions often do not couple well together, and the lack of effective coupling means that catalysts are often required. In soil solutions, catalysis of redox reactions is usually mediated by microbial action. However, if a redox reaction is not thermodynamically favoured in a system, microbial intervention will not change that fact (Sposito & Page, 1985).

There are two major reactions that are dominant when the soil pE falls below -2.0 (Eh < 120 mV); firstly, SO_4^{2-} can be reduced to form S^{2-} and the formation of metal sulphide solids becomes possible (Sposito & Page, 1985; and Bauld, 1986) and secondly, microbial activity tends to degrade large molecular weight organic materials and produce organic acids (Sposito & Page, 1985).

All redox processes in the sediment depend on the positioning of the oxic-anoxic interface (redoxcline). This redoxcline may be within the sediment for well-mixed water bodies, or above the sediment/water interface in stratified water bodies. Baccini (1985), generated a two-box model to describe the chemical interactions for the redoxcline (Fig. 47), and the transport of redox-sensitive species will be governed by the redox gradients (Salomons *et al.*, 1987; and Förstner, 1989). The iron oxide barrier (Fig. 47) will adsorb upwardly-diffusing trace metals and will progressively move upward with sedimentation. The sediment layer above the redoxcline may act as a source of metals to the overlying waters (Förstner, 1989). A similar model was developed by Wada and Seisuwan (1986; Fig. 48) for the chemical interactions within mangal sediments. Both these models use the upward migration of bisulphide as the transport mechanism which allows the transport of metals in anoxic environments (Lu &

Chen, 1977; Salomons, 1985; and Salomons *et al.*, 1987).

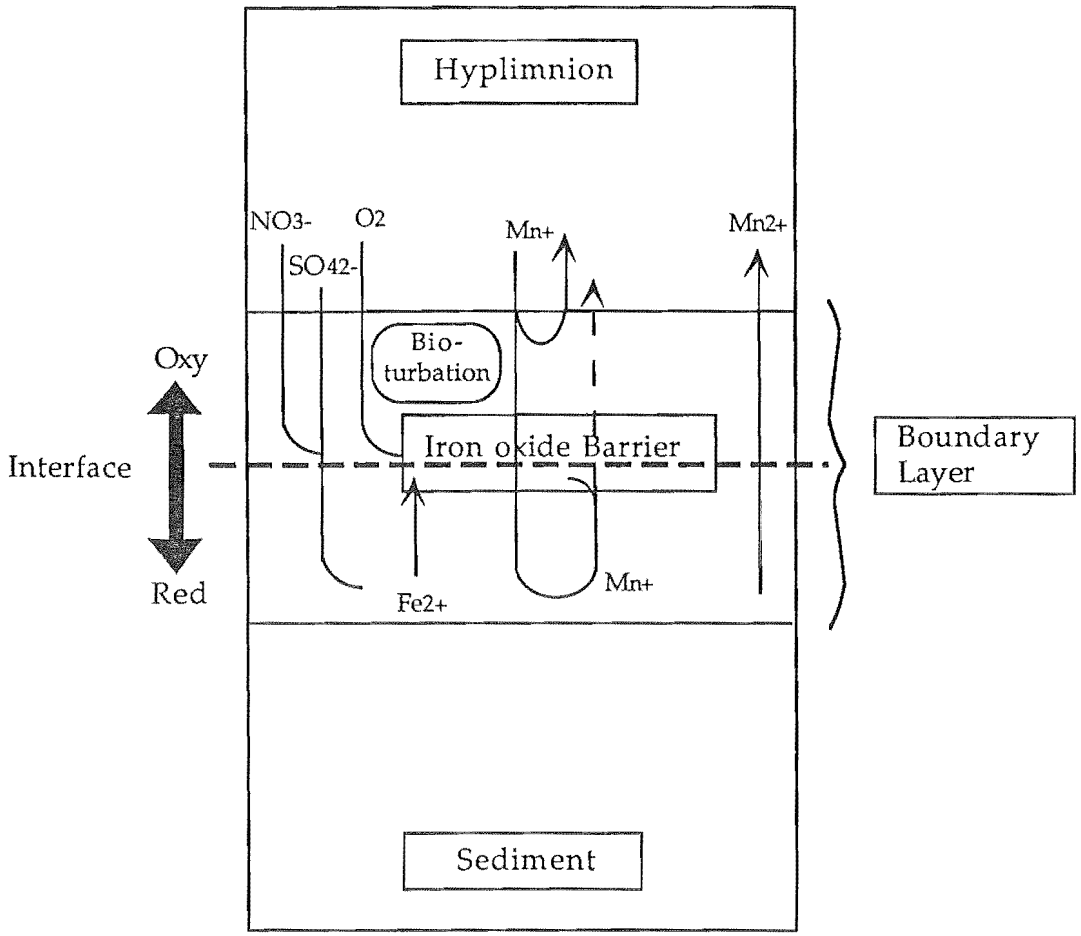


Figure 47 Schematic diagram of metal and nutrient fluxes to and from the sediment (After Baccini, 1985).

Sulphide oxidation, where the sediment dries out and becomes aerated, is another important process involving both Eh and pH changes. Bloomfield and Coulter (1973) show that sulphide oxidation progresses by the following reactions:

$$FeS_2 + H_2O + 7O \longrightarrow FeSO_4 + H_2SO_4$$
$$2\,FeSO_4 + O + H_2SO_4 \longrightarrow Fe_2(SO_4)_3 + H_2O$$
$$Fe_2(SO_4)_3 + FeS_2 \longrightarrow 3\,Fe_2(SO_4)_3 + 2S$$
$$6\,Fe_2(SO_4)_3 + 2S + 8\,H_2O \longrightarrow 12\,FeSO_4 + 8H_2SO_4$$

Large amounts of sulphuric acid are produced by these reactions, lowering soil pH and resulting in mobilisation of many metallic species (Bloomfield & Coulter,

1973; and Dent, 1986). No-ferrous metal sulphides can also be decomposed by a similar sequence of reactions.

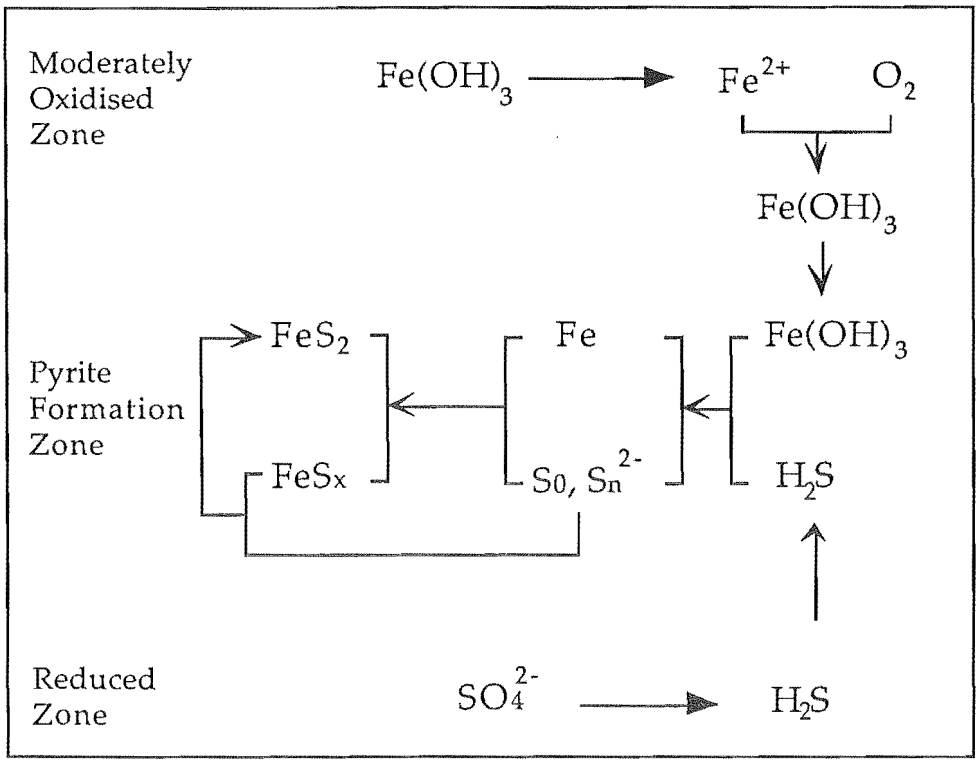


Figure 48 The process of pyrite formation in mangrove soils (After Wada & Seisuwan, 1986).

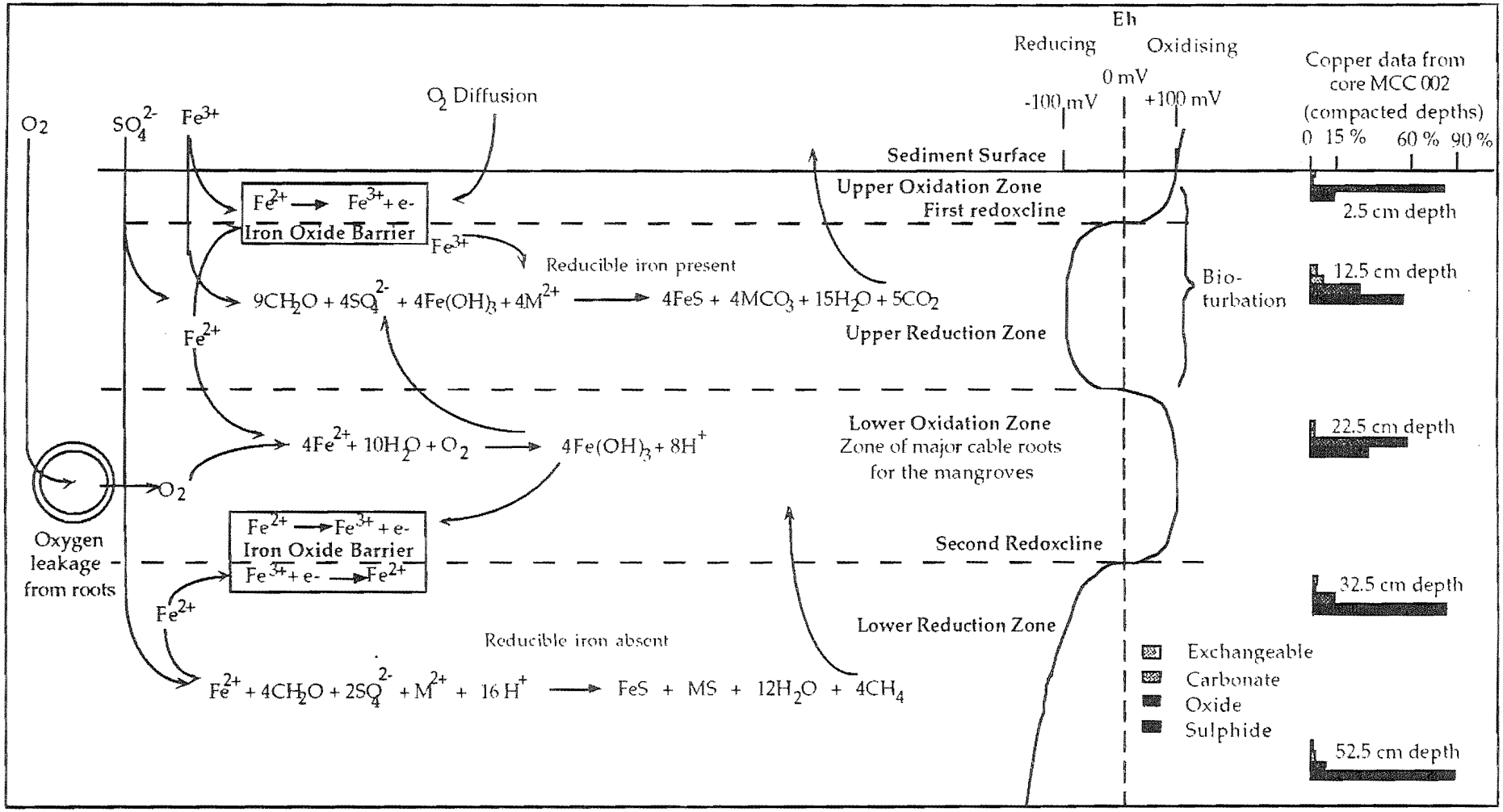
Redox conditions at the Wynnum site are probably the major control on the mobilisation and accumulation of metals. The lateral distributions that were found by Saenger, McConchie and Clark (1991) are very different from those found in this study mostly because a long dry period has caused a rise in Eh of surface sediments. These changes, which developed over 12 months indicate that the metals are mobile and that their mobility responds rapidly to a change in Eh. The only transect that shows a smooth decay curve from the tip to the coast is Transect 1 (Fig. 30), which shows lowered Eh values (< 150 mV) compared to all other transects. There is a rise in metal concentration about two thirds of the way along the transect, corresponding to a sharp fall in the Eh. Most transects show a

similar relationship between rises in metal concentration and sharp falls in Eh.

To the south of the fisherman's access way (**Figs.** 15 & 16), the sediment is well oxygenated and the pH depressed compared to the northern section. The low pH has caused a number of metals to desorb from clay minerals and the oxidation of sulphidic material is evident (free S^{2-} is reduced see **Appendix** 2). The pH has not been lowered enough to cause desorption of Pb (Kinniburgh *et al.*, 1976), and the profile for this element is relatively unchanged from that reported in Saenger, McConchie and Clark (1991).

Transition zones between the dead mangroves and the living mangroves and between the mangrove forest and the mud flats show that there is a sharp increase in Eh and a decrease in pH at depths of about 25 cm. It is likely that this is the depth at which the maximum oxygen loss from mangrove roots is taking place (Armstrong, 1978). The 25 cm depth also corresponds to the depth of maximum deposition of sulphide and oxide material as proposed by Wada and Seisuwan (1986; **Fig.** 48), and would represent the lower redoxcline. A maximum concentration of metals is also evident in the cores at the depth of 20- 30 cm (see, **Appendix** 2), corresponding to this lower redoxcline. At Wynnum, there is good evidence that two redoxclines are present, at the surface and at 25 cm and allows the construction of (**Fig.** 49). Partitioning of metals at the redoxclines shows the influence of upwardly-moving hydrogen sulphide and bisulphide complexes.

Figure 49 Schematic diagram of the chemical fluxes to, from and within the sediments at Wynnum. The depth of the upper and lower redoxclines is dependent n the position within the forest. On the mudflats and within the area of dead mangroves only the upper redoxcline is applicable as the lower redoxcline is absent because the influence of the trees is lost. Sulphate is able to migrate to the levels of the sediment by infiltrating burrows in the upper bioturbated zone. In the upper reduced zone other metals (M) may substitute for iron in the sulphide lattice, or form their own free sulphides.


Eh
Reducing
Oxidising
0 mV
-100 mV
+100 mV
Copper data from core MCC 002 (compacted depths)
0 15 % 60 % 90 %
Sediment Surface
Upper Oxidation Zone
First redoxcline
O2 Diffusion
O2
SO4 2-
Fe3+
Fe2+ → Fe3+ + e-
Iron Oxide Barrier
Fe3+
Reducible iron present
9CH2O + 4SO4 2- + 4Fe(OH)3 + 4M2+ → 4FeS + 4MCO3 + 15H2O + 5CO2
Upper Reduction Zone
Fe2+
Bio-turbation
2.5 cm depth
12.5 cm depth
4Fe2+ + 10H2O + O2 → 4Fe(OH)3 + 8H+
Lower Oxidation Zone
Zone of major cable roots for the mangroves
22.5 cm depth
O2
Oxygen leakage from roots
Fe2+ → Fe3+ + e-
Iron Oxide Barrier
Fe3+ + e- → Fe2+
Second Redoxcline
32.5 cm depth
Fe2+
Lower Reduction Zone
Reducible iron absent
Fe2+ + 4CH2O + 2SO4 2- + M2+ + 16 H+ → FeS + MS + 12H2O + 4CH4
Exchangeable
Carbonate
Oxide
Sulphide
52.5 cm depth

CONCLUSIONS

Summary

The distribution of metals at the Wynnum site is complex and there has been a significant breakdown of the simple decay curves for metals that were reported in Saenger, McConchie and Clark (1991). The breakdown, which appears to be the result of a long dry period, indicates that metals have been remobilised and redistributed in the sediment and may have leached into Moreton Bay.

Lateral distribution of metals at the Wynnum site appear to be primarily controlled by Eh, whereas the vertical distribution is primarily controlled by the abundance of fine sediment, especially the clay fraction. Sharp increases in metal concentration correspond to decrease in sediment Eh. Because metal distribution is so greatly affected by Eh, the very low rainfall conditions in 1991, which have caused sediments to dry and the Eh to rise (drying also increases salinity where tidal inundation is irregular) have caused metals to be redistributed as chloride complexes. Metal mobilisation as a consequence of drying is also aided by sulphuric acid produced as a result of sulphide oxidation when the water table falls; the low pH conditions facilitate desorption of metals from clays, iron oxides, organic matter and sulphides.

Metal transport within the mangroves is by the lower weight organic fractions, which remain mobile under acidic conditions, and as dissolved species, probably primary chloride complexes. Immobilisation of metals in the mangrove forest is primarily by the formation of sulphides produced by bacterial sulphate reduction in areas with low Eh. Sequential cycles of mobilisation and immobilisation result in a progressive seaward movement of metals down the hydraulic gradient. Metal transport through the sediment by groundwater is also very important, especially for the movement of leachate from the tip, but the quantities being transported by this means are unknown.

The rate and direction of leachate movement in the lower sediments is controlled by the underlying weathered basalt, the permeability of the sediment, the positioning of the tidal plane, and the location of small basement highs.

Groundwater data show a rapid rise in highly concentrated leachate entering the deeper sediments about three days after rainfall that is preceded by a long period of dry weather (Fig. 38) confirming the major role played by ground water in leachate dispersion. To reduce environmental concerns about the tip the Brisbane City Council built a leachate interception drain to collect easterly directed leachate. The drain is at depth of about 2.0 m below the manhole cover or about 30 cm below the level of the sediment in the dead mangroves (E.A., Callipolitis, Brisbane City Council, pers com.). This drain, while a positive move by the council, probably falls short of expectations for the removal of the threat from leachate movement for two reasons: firstly the drain appears unable to cope with direct seepage from the sides of the tip cell and secondly, it is unable to interrupt the deeper flow of leachate in ground water (Fig. 45).

Although groundwater appears to be the major mechanism for metals entering sediments near the Wynnum Tips the input via surface runoff is also significant. Surface runoff data collected during this study were collected after the tip was closed and it is likely that metal concentrations are lower than they would have been if samples had been collected while the tip was open. However, the data collected for this work suggest that even after tip closure for every 100 mm of rainfall about: 2.58 g of Pb, 7.63 g of Cu, 52.28 g of Zn, 0.01 g of Hg, 0.05 g of Cr, 7.08 g of Ni and 146.2 g of Fe enter the dead mangroves and the salt marsh.

A high proportion of the metal that enter the dead mangroves is able to pass through this zone because the algae, keep the surficial sediments well oxygenated during the day preventing the metals being immobilised as sulphides. Metals present in the dead mangroves at night, when the area

becomes oxygen deficient, are precipitated as sulphides, but most of the precipitated metals are remobilised on re-oxygenation of the overlying water and continue to migrate toward the trees. The metals also migrate southward along the weakly functioning drainage line that has been blocked by the building of the fisherman's access way. The Eh map (**Fig.** 15) defines where the drainage line has been redirected in an easterly direction and it is at the head of this easterly directed drainage that the highest concentration of metals is found. Another high in metal concentration occurs at the head of a second small drainage line to the north east (**Fig.** 15).

The relationship between the concentration of metals available to plants, sediment characteristics and the metal distribution in the sediment have shown that no single characteristic of the sediment (e.g., TOC, sulphide content, clay content, etc. controls the availability of metal to plants). The only significant correlations were between the total metal content for a sample site and the plant available metals, with Pb R^2 = 0.585, Cu R^2 = 0.832 and Zn R^2 = 0.927. These correlations indicate that the plant available metal is independent of the sediment chemical conditions and that total metal concentrations are the limiting factor. Similarly there was no significant correlation between the concentration of plant available metals in the sediment and the metal concentrations in plants. The lack of relationship between plant available metal concentrations and the metal load in the plants is probably related to the specialised salt management strategies that have evolved in mangroves to enable them to survive exposure to highly saline water.

Data presented here show that the tip is the major source of metals that are now present in the sediments at Wynnum. Data from samples such as core MCC 012 (**Fig.** 35) leave little doubt that other possible sources such as the oil refinery, have a negligible impact on metal levels at Wynnum. However, there is evidence that the discharge of sewage into Crab Creek is responsible for some of the mercury and zinc found in the coastal sediments.

Samples collected during the dry season for this work, confirm the hypothesis of Saenger, McConchie and Clark (1991), that metal trapping in the Wynnum sediments can be reversed, with samples obtained near the sediment surface having much lower metal loads than they do during the wet season. During the dry season, the metal concentrations in sediment 25-50 cm below the surface are higher than they are during the wet season. These seasonal changes in metal distribution show that some of the metal load is redistributed as the water table rises and falls and hence, that the metal concentration in a sediment sample will depend to some extent on the position of the water table relative to the sampling depth. It is also evident that although the mangroves are the primary cause for metal accumulation; the trees are a major factor in the remobilisation of the metals as oxygen leakage from the root system raises Eh and destabilises metal sulphides the previously bound metals.

Recommendations

Reducing metal inflow

There are two ways in which metals may enter the sediments at Wynnum; firstly by surface runoff of rain waters and secondly, by infiltration of groundwater to produce metal bearing leachates. The control of runoff can be readily achieved, but the control of leachate is far more difficult. Furthermore there is a problem in that reducing runoff must increase infiltration and hence metal leaching into the groundwater; consequently, controlling one source of metals may well enhance the effectiveness of the other.

To reduce the metal load in runoff water it is necessary to increase runoff rates to reduce the time that water has to strip metals from the sediments. This course of action will also reduce infiltration and hence leaching, but it will accelerate surface runoff.

Leachate can be intercepted by drains and removed but as shown by this study such drains are not completely effective. The only way to control both

runoff and leachate completely is to seal the site and surround the tip site with leachate interception drains, but these strategies are incompatible with the present environmental setting at Wynnum. Consequently, control of runoff and leachate is not the best option for managing metals at the Wynnum site and protecting the waters of Moreton Bay.

Maintenance of present chemical conditions

The most important environmental protection strategy for the site is to maintain the present chemical conditions in the area to keep the metals bound to the sediments.

The metal trapping mechanisms at Wynnum depends on the presence of fine grained reducing sulphidic sediment and the trapping can be easily reversed (releasing bound metal) if the mangroves are destroyed or the sediment is drained and allowed to oxidise. From an environmental management view point, these observations make a strong case for ensuring that the mangrove belt is preserved in its present form and that neither the mangrove belt nor the unvegetated zone are drained.

The unvegetated zone could in the future be covered with top soil as part of any land development work, but any lowering of the water table must be avoided because the resulting oxidisation of the muds would not only encourage the release of the presently bound metals but would also trigger the formation of acid sulphate soils which would constitute an additional environmental hazard.

Increasing mangrove area

The extension of the area of mangroves is an option that has merit in this area. At present there is a natural extension in the northern section where the trees at the mouth of crab creek are providing a sheltered embayment for the development of seedlings. It is possible to accelerate this natural progression of the shoreline to provide an extension of the chemical conditions and produce a

wider buffer zone between the tip and Moreton Bay. In Bangladesh the planting of mangrove species is well established as a technique to stabilise and accelerate accretion of sediments to provide new agricultural lands (Saenger & Siddiqi, in press, see the references there in). This extension should also include the area of dead mangroves because this would trap metals before they reach the existing mangrove forest; as a result of exposure to cyclic wetting and drying and the presence of an algal cover metals can still move through the area of dead mangroves.

Development options

The presently proposed development options for the Wynnum site are the most commonly employed for old tip sites, which is the creation of sports fields (I. Woods pers. com.). This is an acceptable plan for the Wynnum site because the rate of surface runoff from a grassed area will not be significantly less than for the bare tip and will keep runoff high, while providing some soil stability. It must be stressed that by decreasing runoff there will be an increase in infiltration and thus leachate production. Hence the maintenance of a high runoff status from the tip is strongly advised.

Development options for the remaining salt marsh and the dead mangroves are limited as well. While the area may be infilled any lowering of the water table will have detrimental effects on the bound metals in these areas and within the mangrove forest. Draining will allow the production of acid sulphate soil conditions and metal will be mobilised from the sediments. Even though the acid sulphate soil development may be confined to the area of salt marsh, the sulphuric acid that is produced as a by product of sulphide oxidation, will move down the hydraulic gradient and mobilise metals from sediments that it passes through. Metals mobilised by such an event, which if they reach the coast will be as a concentrated slug, which will have serious environmental consequences for the biota of Moreton Bay.

Any development option that is undertaken for the Wynnum site must consider what effects there will be on the water table. If development will in any way lower the groundwater table, then the development must not be allowed to proceed.

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REFERENCES CITED.

Ajayi, S.O. and Vanloon, G.W. (1989): Studies on redistribution during the analytical fractionation of metals in sediments. *Sci. Tot. Environ.*, 87/88, 171-187.

Aller, R.C. (1978): The effects of animal-sediment interactions on geochemical processes near the sediment-water interface. In *Estuarine Interactions..*, 1st. edn. (Ed:) Academic Press, Inc., , 157-173.

Alloway, B.J. (1990): Soil processes and the behaviour of metals. In: *Heavy Metals in Soils.*, 1st. edn. (Ed: Alloway, B.J.) Blackie and Son Ltd., Glasgow, 7-28.

Anderson, H.A., Hepburn, A., Miller, J.D., Stuart, M., Ferrier, R.C. and Walker, T.A.B. (1990): Humic substance throughflow relationships in two forested ecosystems. *Anal. Chimica Acta*, 232, 3-10.

Andriesse, J.P., Breeman, N. van and Blokhuis, W.A. (1973): The influence of mudlobsters (*Thalassia anomal*) on the development of acid sulphate soils in mangrove swamps in Sarawak (East Malaysia). In: *Acid Sulphate Soils.* (Ed. H. Dorst) Vol. 2. Intern. Inst. Land Reclamation and Improvement, Wageningen, Holland, 11-32.

Armstrong, W. (1978): Root aeration in the wetland condition. In: *Plant Life in Anaerobic environments.* (Eds. D.D. Hook and R.M.M. Crawford), Ann Arbor Science Publishers Inc., Ann Arbor, 269-297.

Armstrong, W. (1982): Chapter 10. Waterlogged soils. In: *Environment and Plant Ecology.* Etherington, J.R., John Wiley & Sons, Chichester. 290-372.

Aylward, G.H. and Findlay, T.J.V. (1989):*SI Chemical Data.* John Wiley & Sons, Hong Kong.136 pp.

Baccini, P. (1985): Phosphate interactions at the sediment water interface. In: *Chemical Processes in Lakes.* (Ed. W. Stumm) John Wiley & Sons, New York,

Barshard, I. (1966): The effect of a variation in precipitation on the nature of clay mineral formation in soils from acidic and basic igneous rocks. *proc. Int. Clay Conf.,Jerusalem*,1,167-173.

Bar-Tal, A., Bar-Yousef, B. and Chen, Y. (1988): Effects of fulvic acid and pH on zinc sorption on montmorillonite. *Soil Sci.*, 146, 367-373.

Bauer, H.H., Christian, G.D. and O'Reilly, J.E. (1978): *Instrumental Analysis.* , Allyn and Bacon, Inc., Boston, 832 pp.

Bauld, J. (1986): Transformations of sulphur species by phototrophic and

chemotrophic microbes. In: *The Importance of Chemical "Speciation" in Environmental Processes.*, (Eds. Bernhard, M., Brinkman, F.E., and Sadler, P.J.), Springer-Verlag, Berlin, 255-273.

Bennett, I. (1968): The mudlobster. *Aust. Nat. Hist.*, 16, 22-25.

Berner, R.A. (1984): Sedimentary pyrite formation: an update. *Geochim. Cosmochim. Acta*, 48, 605-615.

BDH Chemicals (1991): *Chemicals 1991-92.*. BDH Chemicals, Poole, 448 pp.

Bird, E.C.F. (1971): Mangroves as land builders. *Vic. Nat.*, 88, 189-197.

Bloch, J. and Krouse, R.H. (1992): Sulphide diagenesis and sedimentation in the Albian Harmon Member, Western Canada. *J. Sed. Petrol.*, 62, 235-249.

Bloomfield, C. and Coulter, J.K. (1973): Genesis and management of acid sulphate soils. *Adv. Agron.*, 25, 265-326.

Boto, K.G. and Bunt, J.S. (1981): Tidal export of particulate organic matter from a northern Australian mangrove system. *Est. Coast. Shelf. Sci.*, 13, 247-255.

Bouyocos, G.J. (1932): Studies on the dispersion procedure used in the hydrometer method for making mechanical analysis of soils. *Soil Sci.*, 33, 21-26

Branca, M., Micera, G., Dessi, A. and Sanna, D. (1990): Complexation of oxovanadium (IV) by humic and tannic acids. *J. Inorg. Biochem.*, 39, 109-115.

Brookins, D. G. (1986): *Eh - pH diagrams for geochemistry.* Springer-Verlag, New York. 176pp.

Brown, D.A. (1955): Ion exchange in soil plant environments, II, The effects of type of clay mineral upon nutrient uptake by plants. *Soil Sci. Soc. Am. Proc.*, 19, 296-300.

Brümmer, G.W. (1986): Heavy metal species, mobility and availability in soils. *In* : *The Importance of Chemical "Speciation" in Environmental Processes.* (Eds. M. Bernard, F.E. Brinckman and P.J. Sadler) Springer-Verlag, Berlin, 169-192.

Campbell, P.G.C. and Tessier, A. (1987): Current status of metal metal speciation studies. In:*Metals Speciation, Separation and Recovery.* 1st edn. (Eds: Patterson J.W. and Pussino R.) Lewis Publishers Inc., Chelsea (Michigan), 201-224.

Carroll, D. (1959): Ion exchange in clays and other minerals. *Geol. Soc. Am. Bull.*, 70, 749-780.

Chao, L.L. (1972): Selective dissolution of manganese oxides from soils and sediments with acidified hydroxlamine hydrochloride. *Soil Sci. Soc. Am. Proc.*, 36, 764-768.

Chao, T.T. and Theobald, P.K. Jr. (1976): The significance of secondary iron and manganese oxides in geochemical exploration. *Econ. Geol.*, 71, 1560-1569.

Chemtronics, (1986): *The Portable Digital Voltammeter PDV 2000 Instruction Manual.* Park Printing Co., Perth, 86 pp.

Chester, R. and Hughes, M.J. (1967): A chemical technique for the separation of ferro-manganese minerals, carbonate minerals, and adsorbed trace elements from pelagic sediments. *Chem. Geol.*, 2, 233-248.

Clarke, L.D. and Hannon, N.J. (1967): The mangrove swamp and the salt marsh communities of the Sydney district. I. Vegetation, soils and climate. *J. Ecol.*, 55, 753-771.

Clesceri, L.S., Greeberg, A.E. and Tressell, R.R. (Eds.) (1989): *Standard Methods for the Examination of Water and Wastewater.* , 17 th edn., American Public Health Association., Washington D.C., 1466 pp.

Cooper, B.S. and Harris, R.C. (1974): Heavy metals in organic phases of river and estuarine sediments. *Mar. Poll. Bull.*, 5, 24-26.

Coordinator General's Department, Queensland (1974): *Coastal Management Investigation. Queensland - New South Wales Border to Northern Boundary of Noosa Shire. Meteorology and Oceanography.*

Dent, D. (1986): *Acid sulphate soils: a baseline for research and development.* Internat. Inst. for Land Reclamation and Improvement, Wageningen, Netherlands,

Deurer, R., Förstner, U. and Schmoll, G. (1978): Selective chemical extraction of carbonate - associated metals from recent lacustrine sediments. *Geochim. Cosmochim. Acta*, 42, 425-427.

Dowling, R.M. (1986): *The Mangrove Vegetation of Moreton Bay.* Queensland Botany Bulletin, No 6. Queensland Department of Primary Industries, Brisbane. 45 pp.

Duff, S.J., Hay, G.W., Micklethwaite, R.K. and Vanloon, G.W. (1989): Distribution and classification of metal species in soil leachates. *Sci. Tot. Environ.*, 87/88, 189-197.

Dutta, D., Mandal, B. and Mandal, L.N. (1989): Decrease in the availability of zinc and copper in acidic to near neutral soils on submergence. *Soil Sci.*, 147, 187-195.

Ellis, B.G. and Knezek, B.D. (1972): Adsorption reactions of micronutrients in soils. In: *Micronutrients in Agriculture.* (Eds. J.J. Mortvedt, P.M. Giordano and W.L. Lindsay). Soil Science Society of America, Inc., Madison, 59-78.

Emerson, S., Jahnke, R. and Heggie, D. (1984): Sediment-water exchange in shallow water estuarine sediments. *J. Mar. Res.*, 42, 709-730.

Engler, R.M., Brannon, J.M., Rose J. and Bigham, G. (1977): A practical selective

extraction procedure for sediment characterisation. In: *Chemistry of Marine Sediments*. (Ed. Yen T.F.), Ann. Arbor. Sci. Publ.,Ann. Arbor., 163-180.

Ephriam, J.H., Marinsky, J.A. and Cramer, S.J. (1989): Complex-forming properties of natural organic acids. Fulvic acid complexes with Cobolt, Zinc and Europium. *Talanta*, 36, 437-443.

Follett, E.A.C. (1965): The retention of amorphous, colloidal 'ferric hydroxide' by kaolinites. *J. Soil. Sci.*, 16, 334-341.

Fonseca, M.S. (1989): Sediment stabilisation by *Halophila decipiens* in comparison to other seagrasses. *Est. Coast. Shelf. Sci.*, 29, 501-507.

Förstner, U. (1989): *Contaminated Sediments*. Lecture Notes in Earth Science, #21. 1st edn. Springer-Verlag, Amsterdam. 157 pp.

Förstner, U. and Salomons, W. (1980): Trace metal analysis on polluted sediments. Assessment of sources and intensities. *Environ. Technol. Lett.*, 1, 494-505.

Förstner, U. and Wittmann, G.T.W. (1981): *Metal pollution in the aquatic environment*. Springer - Verlag, Berlin, pp.

Freisser, H. and Morrison, G.H. (1959): Solvent extraction in radiochemical separations.*Ann. Rev. Nucl. Sci.*, 9, 221-244.

Frey, R.W., Howard, J.D., Han, S.J. and Park, B.K. (1989): Sediments and sedimentary sequences on a modern macrotidal flat, Inchon, Korea.*J. Sed. Petrol.* 59 28-440.

Fritz, J.S. and Schenk, G.H. (1979): *Quantitative Analytical Chemistry*. 4 th edn., Allyn and Bacon, Inc., Boston, 661 pp.

Gadow, S. (1970): 1. Sedimente und chemismas. In: *Das Watt, Ablgerungs - und Lebensraum*. Reineck, H.E. Ed., W. Kramer, Frankfurt, 33-35.

Garland, G.A., and Mosher, D.C. (1975): Leachate effects of improper land disposal. *Waste Age.*, March, 42-48.

Gavis, J., and Ferguson, J.F. (1972): The cycling of mercury through the environment. *Water Res.*, 6, 989-1008.

Gentilli, J. (1972): *Australian Climatic Patterns*. Thomas Nelson (Australia) Ltd., Melbourne. 285 pp.

Gerdes, G., Krumbein, W.E. and Reineck, H.E. (1985): The depositional record of sandy, versicolored tidal flats (Mellum Island, Southern North Sea). *J. Sed. Petrol.* 55 265-278.

Gibbs, R.J. (1977): Transport phases of transition metals in the Amazon and Yukon Rivers. *Geol. Soc. Am. Bull.*. 88, 829-843.

Gillman, G.P. and Sumpter, E.A. (1986): Modification to the compulsive exchange method for measuring exchange characteristics of soils. *Aust. J. Soil Res.*, 24, 61-66.

Gjessing, E.T., Riise, G., Petersen, R.C. and Andruchow, E. (1989): Bioavailability of aluminium in the presence of humic substances at low and moderate pH. *Sci. Tot. Environ.*, 81/82, 683-690.

Gleason, M.L. and Zieman, J.C. (1981): Influence of tidal inundation on internal oxygen supply of *Spartina alterniflora* and *Spartina patens*. *Est. Coast. Shelf. Sci.*, 13, 47-57.

Grim, R.E. (1968): *Clay Mineralogy*. McGraw-Hill Book Company, New York. 596 pp.

Gupta, S.K. and Chen, K.Y. (1975): Partitioning of trace metals in selective chemical fractions of near-shore sediments. *Environ. Lett.*, 10, 129-158.

Hamblin, W.E. (1962): X-ray radiography in the study of structures in homogeneous sediments. *J. Sed. Petrol.* 32, 201-210.

Hansen, M.H., Ingvorsen, K. and Jørgensen, B.B. (1978): Mechanisms of hydrogen sulphide release from coastal marine sediments to the atmosphere. *Limnol. Oceanogr.* 23, 68-76.

Harbison, P. (1986): Mangrove mud: A sink and source for trace metals. *Mar. Poll. Bull.*, 17, 246-250.

Heckel, H., Jones, M. and Searle, D.E. (1976): Relict sediments in Moreton Bay. *Queensland Government Mining Journal*, 77, 36-45.

Heckel, H., Ward, W.T., Jones, M. and Searle, D.E. (1978): Geological development of Northern Moreton Bay. In: *Northern Moreton Bay Symposium*. 1st. edn., (eds. Bailey, A. and Stevens, N.C.), Royal Society of Queensland, Brisbane, 7-18.

Hinckley, D.N. (1963): Variability in "crystallinity" values among kaolin deposits of the coastal plain of Georgia and South Carolina. *Clays. Clay Min.*, 13, 229-235.

Hirner, A.V., Kritsotakis, K. and Tobschall, H.J. (1990): Metal-organic associations in sediments-I. Comparison of unpolluted recent and ancient sediments and sediments affected by anthropogenic pollution. *Appl. Geochem.*, 5, 491-505.

Holmgren, G.G.S. (1967): A rapid citrate-dithionite extractable iron procedure. *Soil Sci. Soc. Am. Proc.*, 31, 210-211.

Hook, D.D. and Scholtens, J.R. (1978): Adaptations and flood tolerance of tree species. In: *Plant Life in Anaerobic environments*. (Eds. D.D. Hook and R.M.M. Crawford) Ann Arbor Science Publishers Inc., Ann Arbor, 299-331.

Huang, C.P., Hsieh, Y.S., Park, S.W., Corapcioglu, M.O., Bowers, A.R. and Elliott, H.A. (1987): Chemical interactions between heavy metal ions and hydrous solids. In: *Metals Speciation, Separation, and Recovery.* (Eds. J.W. Patterson & R. Passino) Lewis Publishers, Inc., Chelsea, 439-465.

Hutchings, P. and Saenger, P. (1987): *Ecology of mangroves.* University of Queensland Press, Brisbane, 388pp.

Inoue, K., Zhao, L.P. and Huang, P.M. (1990): Adsorption of humic substances by hydroxyaluminium- and hydroxyaluminosilicate- montmorillonite complexes. *Soil Sci. Soc. Am. J.,* 54, 1166-1172.

Jackson, M.L. (1958): *Soil Chemical Analysis.,* Prentice Hall, Englewood Cliffs, N.J., 498 pp.

Jaya, S., Rao, T.P. and Rao, G.P. (1985): Simplified anodic-stripping voltammetric determination of mercury in sea water using a glassy carbon electrode and an acetate-chloride buffer. *Analyst,* 110, 1361-1364.

Jenne, E.A. (1977): Trace element sorption: sediments and soils. In: *Molybdenum in the Environment.* Vol. 2. (Eds. Chapple, W and Peterson, K.G.) Marcel Dekker Inc., 425-552.

Jennings, D.H. (1968): Halophytes, succeedance and sodium - a unified theory. *New Phyt.,* 67, 899-911.

John, J., Salbu, B., Gjessing, E.T. and Bjørnstad, H. (1988): Effect of pH, humus concentration and molecular weight on conditional stability constants of cadmium. *Water Res.,* 22, 1381-1388.

Jonasson, I.R. (1977): Geochemistry of sediment/water interactions of metals, including observations on availability. In: *The Fluvial Transport of Sediment-Associated Nutrients and Contaminants.* (Eds. H. Shear and A.E.P. Watson) IJC/PLURARG, Windsor, 255-271.

Jørgensen, B.B. (1982): Ecology of the bacteria of the sulphur cycle with special reference to anoxic-oxic interface environments. *Phil. Trans. Roy. Soc. London,* B298, 543-561.

Jørgensen, S.E. and Jensen, A. (1985): Processes of metal ions in the environment. In: *Metals Ions in Biological Systems.* (Ed. H. Sigel) Circulation of Metals in the Environment.Vol. 18. Marcel Dekker, Inc., New York, 61-103.

Kersten, M. and Förstner, U. (1986): Chemical fractionation of heavy metals in anoxic estuarine and coastal sediments. *Water Sci. Technol.,* 18, 121-130.

Kester, D.R. *et al.* (Eds.) (1983): *Wastes in the Ocean, Vol. 2: Dredged Material Disposal in the Ocean.,* Wiley, New York, 299 pp.

Khalid, R.A., Grambrell, R.P. and Patrick, W.H. Jr. (1981): Chemical availability of

cadmium in Mississippi River sediment. *J. Environ. Qual.*, 10, 523-528.

Kinniburgh, D.G., Jackson, M.L. and Syers, J.K. (1976): Adsorption of alkaline earth and heavy metal cations by hydrous oxide gels of iron and aluminium. *Soil Sci. Soc. Am. J.*, 40, 796-799.

Koeppe, C.E. and Long, G.C. (1958): *Weather and Climate.* Krieger, Melbourne. 341 pp.

Krom, M.D. and Sholkovitz, E.R. (1978): On the association of iron and manganese with organic matter in anoxic marine pore waters. *Geochim. Cosmochim. Acta*, 42, 607-611.

Lewis, D.W. (1984): *Practical Sedimentology.* Hutchinson Ross Publishing Company, Stroudsburg, 229 pp.

Lindacre, E. and Hobbs, J. (1977): *The Australian Climatic Environment.* Wiley Press, Brisbane. 354 pp.

Lindsay, W.L. and Norvell, W.A. (1978): Development of a DTPA soil test for zinc, iron, manganese, and copper. *Soil Sci. Soc. Am. J.*, 42, 421-428.

Lion, L.W., Altman, R.S. and Lecie, J.O. (1982): Trace-metal adsorption characteristics of estuarine particulate matter: evaluation of contributions of Fe/Mn oxide and organic surface coatings. *Environ. Sci. Tech.*, 16, 660-666.

Louma, S.N. (1990): Processes affecting metal concentrations in estuarine and coastal marine sediments. In: *Heavy metals in the marine environment.* (Eds: Furness R.W.; Rainbow P.S.) C.R.C. Press Inc., Boca Raton, 51-65.

Lu, C.S.J. and Chen, K.Y. (1977): Migration of trace metals in interfaces of seawater and polluted surficial sediments. *Environ. Sci. Technol.*, 11, 174-182.

Luther, G.W.(III), Meyerson, A.L., Krajewski, J.J. and Hires, R. (1980): Metal sulphides in estuarine sediments. *J. Sed. Petrol.*, 50, 117-1120.

Mackey, D.J. and O'Sullivan, J.E. (1990): Metal-organic interactions in sea water: an ecosystem experiment. *Anal. Chimica Acta*, 232, 161-170.

Macnae, W. (1966): Mangroves in eastern and southern Australia. *Aust. J. Bot.*, 14, 67-104.

Malcolm, R.L. (1990): The uniqueness of humic substances in each soil, stream and marine environments. *Anal. Chimica Acta*, 232, 19-30.

Manahan, S.E. (1990): *Environmental Geochemistry.* 4th edn. Lewis Publishers Inc., Chelsea (Michigan). 612 pp.

McBride, M.B., Mortland, M.M. and Pinnavaia, T.J. (1975): Exchange ion positions in smectite: effects on electron spin resonance of structural iron. *Clays and Clay*

Minerals, 23, 162-164.

McCarthy, J.F. and Zachara, J.M. (1989): Subsurface transport of contaminants. Mobile colloids in the subsurface environment may alter the transport of contaminants. *Environ. Sci. Technol.*, 25, 496-502.

McConchie, D.M. (1987): Nutrient transport by inorganic colloids. *Workshop on Nutrients in the Great Barrier Reef.* Townsville. 161-171.

McConchie, D.M. and Lawrance, L.M. (1991): The origin of high cadmium loads in some bivalve molluscs from Shark Bay, Western Australia: A new mechanism for cadmium uptake by filter feeding organisms. *Archives of Environ. Contam. & Toxicol.* 21, 303-310.

McConchie, D. and Saenger, P. (1991): Mangrove forests as an alternative to civil engineering works in coastal environments of Bangladesh: lessons for Australia. *Proceedings of 1990 Workshop on Coastal Zone Management.* Yepoon, Queensland. 220-233.

Mirave, J.P. and Orioli, G.A. (1989): Zinc adsorption and transport from complete humate and medium molecular weight fractions. *Sci. Tot. Environ.*, 81/82, 679-682.

Molenar, N. (1986): The interrelation between clay infiltration, quartz cementation, and compaction in lower Givetian terrestrial sandstones, northern Ardennes, Belgium. *J. Sed. Petrol.*, 56, 359-369.

Montgomery, J.R. and Price, M.T. (1979): Release of trace metals by sewage sludge and the subsequent uptake by members of a turtle grass mangrove ecosystem. *Environ. Sci. & Technol.*, 13, 546-549.

Morgan, J.J. (1987): General affinity concepts, equilibria and kinetics in aqueous metal chemistry. In : *Metals Speciation, Separation and Recovery.* (Ed. J.W. Patterson & R. Pussino) Lewis Publishers Inc., Chelsea (Michigan), 27-63.

Morris, A.W., Bale, A.J. and Howland, R.M.J. (1982): The dynamics of estuarine manganese cycling. *Estuar. Coastal Shelf Sci.*, 13, 175-192.

Murray, H.H. and Lyons, S.C. (1956): Degree of crystal perfection of kaolinite. *Clays Clay Minerals Proc. Fourth Conf.* Natl. acad. Sci. Publ. 456, 455-464.

Nelson, T.A. (1983): Time and method dependent size distributions of fine-grained sediments. *Sed.*, 30, 249-259.

Nissenbaum, A. and Swaine, D.J. (1976): Organic matter-metal interactions in recent sediments: the role of humic substances. *Geochim. Cosmochim. Acta*, 40, 809-816.

Nye, L.B. (1990): Trace Metal Accumulation Under Differing Sediment Conditions in the Mangrove, *Rhizophora mangal* L., in Key Largo, Florida. M.S., Marine

Biology and Fisheries, University of Miami. 50 pp.

Olmstead, L.B. (1931): Dispersion of soils by a supersonic method. *J. Agric. Res.*, 42, 841-852.

Olson, G.J. (1986): Microbial intervention in trace metal-containing process streams and waste products. In: *The Importance of Chemical "Speciation" in Environmental Processes.* (Ed. M. Bernard, F.E. Brinkman & P.J. Sadler) Springer-Verlag, Berlin, 493-513.

O'Melia, C.R. (1989): Particle-particle interactions in aquatic systems. *Colloids and Surfaces*, 39, 255-271.

Papadopoulos, P. and Rowell, D.L. (1988): The reactions of cadmium with calcium carbonate surfaces. *J. Soil Sci.*, 39, 23-36.

Patchineelan, S.R. (1975): *Untersuchunger über die Hauptbindungsarten und die moiliserbarkeit Von Schwertmetallen in fluviatilen sedimenton.* Thesis, University of Heidelberg: FRG.

Pauli, F.W. (1975): Heavy metal humates and their behaviour against hydrogen sulphide. *Soil Sci.*, 119, 98-105.

Pellenbarg, R. (1981): Trace metal partitioning in the aqueous surface microlayer of a salt marsh. 13, 113-117.

Pederson, T.F., Waters, R.D. and MacDonald, R.W. (1989): On the natural enrichment of cadmium and molybdenum in the sediments of Ucluelet Inlet, British Columbia. *Sci. Tot. Environ.*, 79, 125 - 139.

Peterson, P.J., Burton, M.A., Gregson, M., Nye, S.M. and Porter, E.K. (1979): Accumulation of tin by mangrove species in West Malaysia. *Science of the Total Environment*, 11, 213-221.

Petronio, B.M., Campanella, L., Ferri, T. and Pupella, A. (1989): Composition of organic matter in an urban sludge and metal transport. Part II: treatment with $SO_2.H_20$ solutions. *Annali di Chimica*, 79, 15-25.

Piccolo, A. and Mbagwu, J.S.C. (1989): Effects of humic substances and surfactants on the stability of soil aggregates. *Soil Sci.*, 147, 47-54.

Potts, P.J. (1987): *A handbook of silicate rock analysis.* Blackie & Son Ltd., Glasgow, 622pp.

Puls, R.W. and Bohn, H.L. (1988): Sorption of cadmium, nickel and zinc by kaolinite and montmorillonite suspensions. *Soil Sci. Soc. Am. J.*, 52, 1289-1292.

Quirk, J.P. and Posner, A.M. (1975): Trace element adsorption by soil minerals. In: *Trace Elements in Soil-Plant-Animal Systems.* (Ed. D.J.D. Nicholas and A.R. Egan) Academic Press, Inc., New York,

Rapin, R. and Förstner, U. (1983): Sequential Leaching techniques for particulate metal speciation: the selectivity of various extractants. In: *Proceedings 4th Int. Conf. on Heavy Metals in the Environment.*, Heidelberg (Edinbrough, U.K.: CEP Consultants.), 1074-1077.

Rapin, F., Tessier, A., Campbell, P.G.C. and Carigan, R. (1986): Potential artifacts in the determination of metal partitioning in sediments by a sequential extraction procedure. *Environ. Sci. Tech.*, 20, 826-840.

Raspor, B. (1989): Adsorption of humic substances at differentially charged surfaces. *Sci. Tot. Environ.*, 81/82, 213-223.

Reynoldson, T.B. (1987): Interactions between sediment contaminants and benthic organisms. *Hydrobiologia*, 149, 53-66.

Rice, D.L. and Windom, H.L. (1982): Trace metal transfer associated with the decomposition of detritus from estuarine macrophytes. *Bot. Mar.*, 15, 213-223.

Rickard, D.T. (1973): Sedimentary iron sulphide formation. In: *Acid Sulphate Soils.*, (Ed. Dorst, H.), ILRI, Wageningen, Netherlands, Publ. 18, Vol. 1: 28-65.

Rieneck, H.E. and Singh, I.B. (1975): *Depositional Sedimentary Environments.* Springer-Verlag, Berlin. 439 pp.

Rosler, H.J. and Lange, H. (1972): *Geochemical Tables.* Elsevier, Amsterdam.

Saenger, P. and Siddiqi, N.A. (in press): Land from the sea: the mangrove afforestation program of Bangladesh. *J. Ocean and Shoreline Management.*

Saenger, P., McConchie, D. and Clark, M. (1991): Mangrove forests as a buffer between anthropogenically polluted areas and the sea. 1990 Workshop on Coastal Zone Management. Yeppoon, Queensland. 1. 280-300.

Saenger, P., Specht, M., Specht, R.L. and Chapman, V.J. (1977): Mangal and coastal salt-marsh communities in Australasia. In: *Ecosystems of the world. Volume I. Wet Coastal Ecosystems.* (Ed. Chapman V.J.), Elsevier, Amsterdam. 293-345.

Salomons, W. (1985): Sediments and water quality. *Environ. Tech. Lett.*, 6, 315-368.

Salomons, W. and Förstner, U. (1984): *Metals in the Hydrocycle.* Springer-Verlag,Berlin. 349 pp.

Salomons, W. and Mook, W.G. (1980): Biogeochemical processes affecting metal concentrations in lake sediments (IJsselmeer, The Netherlands). *Sci. Total Environ.*, 16, 217-229.

Salomons, W., deRooji, N.M., Kerdiijk, H. and Bril, J. (1987): Sediments as a source for contaminants? *Hydrobiol.*, 149, 13-30.

Schindler, P.W. (1985): Surface complexation. In: *Metals Ions in Biological Systems.* (Ed. H. Sigel) Circulation of Metals in the Environment.Vol. 18. Marcel Dekker, Inc., New York, 105-135.

Schofield, R.K. and Samson, H.R. (1953): The deflocculation of kaolinite suspensions and the accompanying changes from positive to negative chloride adsorption. *Clay Mins. Bull.*, 2, 45-51.

Schwertmannn, U (1964): Differenzierung der eisenoxide des bodens durch photochemische extraktion mit sauerer ammonimoxalat-Lösung. Z. Pflanzenernähr. *Düng. Bodenkde,* 105, 194-202.

Scoffin, T.P. (1970): The trapping and binding of subtidal, carbonate sediments by marine vegetation in Bimi Lagoon, Bahamas. *J. Sed. Petrol.*, 40, 249-273.

Seki, H., Suzuki, A. and Kashiki, I. (1990): Adsorption of lead ions on immobilised humic acid. *J. Colloi and Interface Sci.*, 134, 59-65.

Senaraten, A. and Dissanayake, C.B. (1989): The geochemistry of mercury in some coastal sediments fro Sri Lanka. *Chem. Geol.*, 75, 183-190.

Shanmukhappa, H. and Neelakantan, K. (1990): Influence of humic acid on the toxicity of copper, cadmium and lead to the unicellular algae, *Synechosystis Aquatilis. Bull. Environ. Contam. Toxicol.*, 44, 840-843.

Shepard, S.A. and Thomas, I.M. (1989): *Marine Invertabrates of South Australia. Part II.* South Australian Government Printing Division, Adelaide. 900 pp.

Sherman, D.G. (1952): The genesis and morphology of the aluminia-rich laterite clays. In: *Problems of Clay and Latterite Genesis.* Amer. Inst. Min. Mettall. Engr., New York, 154-161.

Sohn, M. and Rajski, S. (1990): The adsorption of Cd(II) from seawater by humic acids of various sources and origin. *Organic Geochem.* 15, 439-447.

Sposito, G. and Page, A.L. (1985): Cycling of metal ions in the soil environment. In: *Metal Ions in Biological Systems.* (Ed. A. Sigel) Marcel Dekker, Inc., New York, 287-332.

Stackhouse, R.A. and Benson, W.H. (1989): The effect of humic acid on the toxicity and bioavailability of trivalent chromium. *Ecotox. Environ. Safety,* 17, 105-111.

Stanley, J.K. and Byrne, R.H. (1990): Inorganic complexation of Zn(II) in seawater. *Geochim. Cosmochim. Acta,* 54, 753-760.

Stephens, W.M. (1962): Tree that makes land. *Sea Front.*, 8, 219-230.

Stevens, G.N. and Rogers, R.W. (1979): The macrolichen flora from the mangroves of Moreton Bay. *Proc. Royal Soc. Queensland.* 90, 109-120.

Stevenson, F.J. and Ardakani, M.S. (1972): Organic matter reactions involving micronutrients in soils. In: *Micronutrients in Agriculture.* (Eds. Mortvedt, J. J., Giordano, P.M., and Lindsay, W.L.), Soil Science Society of America, Inc., Madison, 79-114.

Stover, R.C., Sommers, L.E. and Silviera, D.J. (1976): Evaluation of metals in waste water sludge. *J. Water Pollut. Cont. Fed.*, 48, 2165-2175.

Summers, A.O. and Silver, S. (1978): Microbial transformations of metals. *Ann. Rev. Microbiol.*, 32, 637-672.

Tessier, A., Campbell, P.G.C. and Bisson, M. (1979): Sequential extraction procedure for the speciation of particulate trace metals. *Anal. Chem.*, 51, 844-850.

Tessier, A., Campbell, P.G.C. and Bisson, M. (1982) Particulate trace metal speciation in stream sediments and relationships with grain size: Implications for geochemical exploration. *J. Geochem. Explor.*, 16 77-104.

Thomas, G.W. (1982): Exchangeable cations. In: *Methods of Soil Analysis, Part 2. Chemical and Microbiological Properties.*, 2nd. Edn., ASA-SSSA, Madison., Agronomy Monograph no. 9. 159-165.

Thomas, C. and Eong, O. J. (1984): Effect of heavy metals zinc and lead on *Rhizophora mucronata Lam.* and *Avicennia alba Bl.* seedlings. *Proc. As. Symp. Mangr. Env. Res. Manag.*, 568-574.

Thomson, E.A., Luoma, S.N., Cain, D.J. and Johansson, C. (1980): The effect of sample storage on the extraction of Cu, Zn, Fe, Mn and organic material from oxidised estuarine sediments. *Water, Air, Soil Poll.*, 14, 215-233.

van Dam, D. and Pons, L.J. (1973): Some micromorphological observations on pyrite reaction products related to its oxidation. In: *Acid Sulphate Soils.*, (Ed. Dorst, H.), ILRI, Wageningen, Netherlands, Publ. 18, Vol. 2: 169-196.

Vasconcelos, M.T.S.D., Santos, A.P.L.M.G. and Machado, A.A.S.C. (1989): Evidence of conformational changes in fulvic acids from dialysis. *Sci. Tot. Environ.*, 81/82, 489-499.

Volkov, I.I. and Formina, L.S. (1974): Influence of organic material and processes of sulphide formation on distribution of some trace elements in deep-water sediments of Black Sea. *Am. Ass. Pet. Geol. Mem.*, 20, 456-476.

Wada, H. and Seisuwan, B. (1986): The process of pyrite formation in mangrove soils. In: *Selected Papers of the Dakar Symposium on Acid Sulphate Soils.*, (Ed. Dorst, H.), ILRI, Wageningen, Netherlands. 24-37.

Walkley, A. and Black, I.A. (1934): An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.*, 37, 29-38.

Waller, P.A. and Pickering, W.F. (1990): Evaluation of "labile" metal in sediments by anodic stripping voltammetry. *Talanta*, 37, 981-993.

Walsh, G.E.R., Ainsworth, K.A. and Rigby, R. (1979): Resistance of red mangrove (Rhizophora mangle L.) seedlings to lead, cadmium, and mercury. *Biotropica*, 11, 22-27.

Weaver, C.E. (1989): *Clays, Muds, and Shales.* Elsevier, Amsterdam. 819 pp.

Weis, M., Abbt-Braun, G. and Frimmel, F.H. (1989): Humic-like substances from landfill leachates - characterisation and comparison with terrestrial and aquatic humic substances. *Sci..Tot. Environ..*, 81/82, 343-352.

Willett, I.R. and Beech, T.A. (1987): Determination of organic carbon in pyritic and acid sulphate soils. *Commun. Soil Sci. Plant Anal.*, 18, 715-724.

Willett, I.R. and Walker, P.H. (1982): Soil morphology and distribution of iron and sulphur fractions in a coastal flood plain toposequence. *Aust. J. Soil Res.*, 21, 283-294.

Wood, J.M. (1987): Biological process involved in the cycling of elements between soil or sediments and the aqueous environment. *Hydrobiologia*, 149, 31-42.

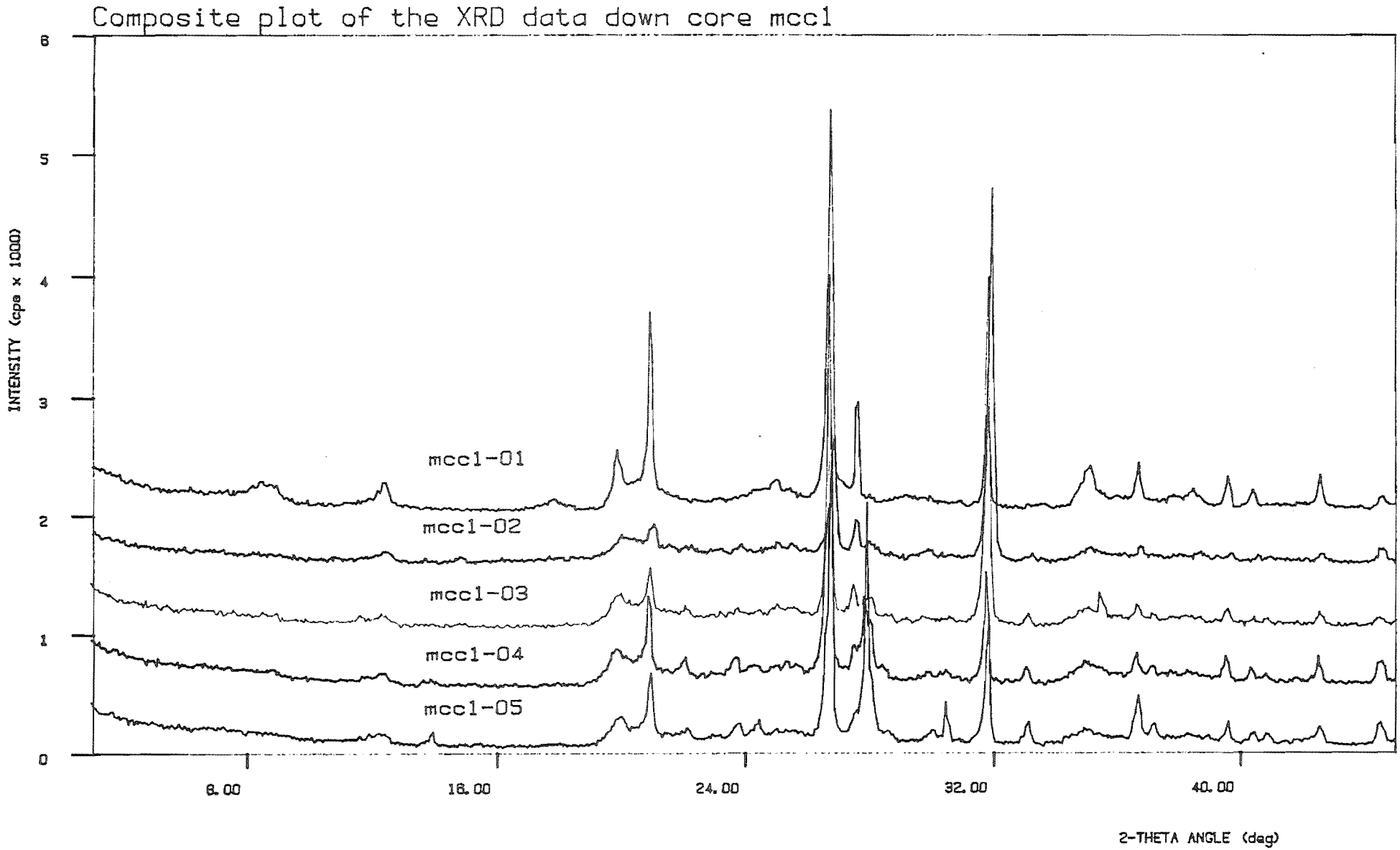
Yamamoto, S. and Ishiwatari, R. (1989): A study of the formation mechanism of sedimentary humic substances - II. Protein-based melanoidin model. *Org. Geochem.*, 14, 479-489.

Yariv, S. and Cross, H. (1979): *Geochemistry of Colloid Systems. For Earth Scientists.* Springer-Verlag, Berlin. 450 pp.

Yoeman, S., Sterrit, R.M., Rudd, T. and Lester, J.N. (1989): Particle size fractionation and metal distribution in sewage sludges. *Water, Air, Soil, Poll.*, 45, 27-42.

Zuberer, D.A. and Silver, W.S. (1978): Biological dinitrogen fixation (acetylene reduction) associated with Florida mangroves. *Appl. Environ. Microbiol.*, 35, 567-575.

Appendix 1 - 1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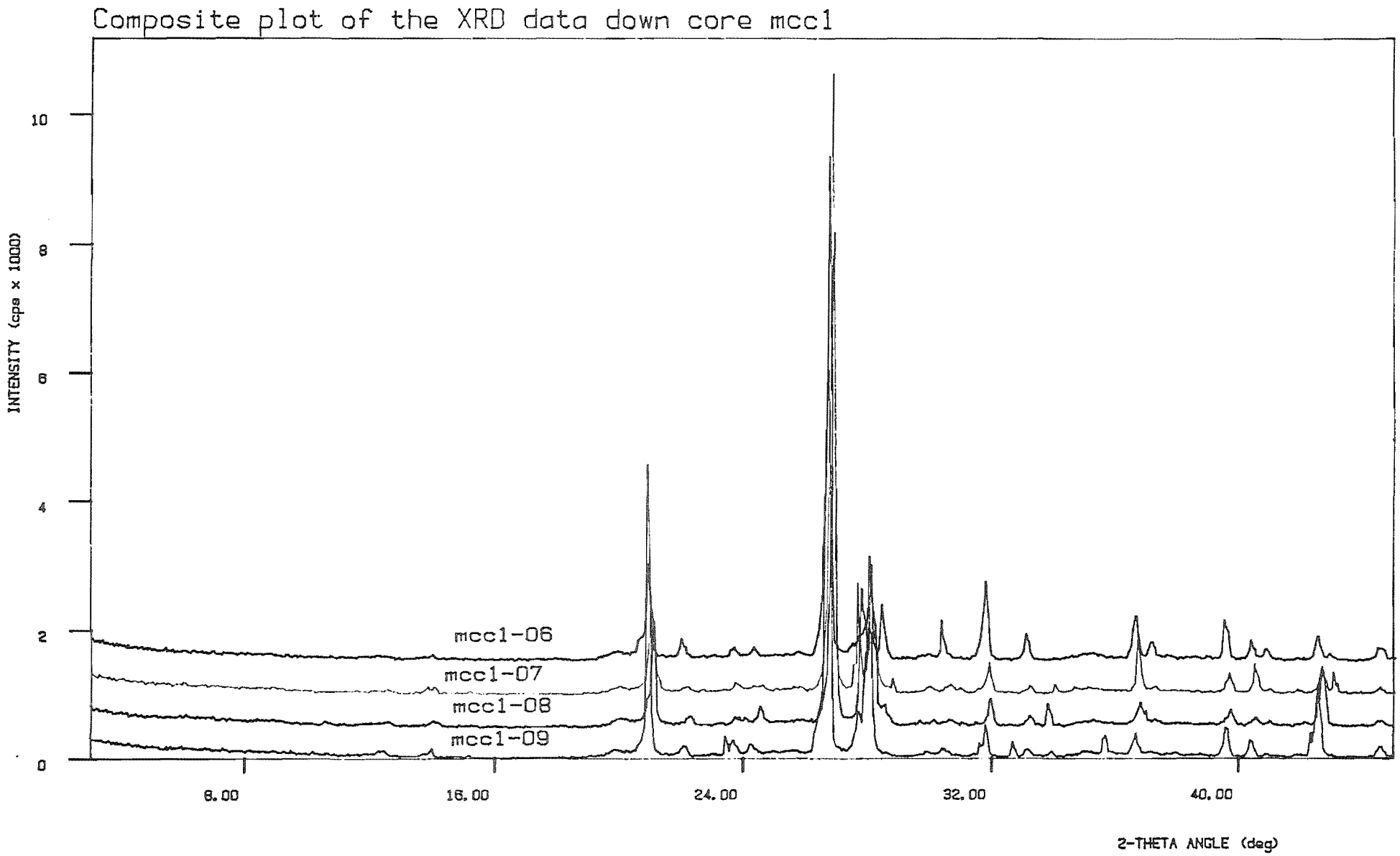
1
2
3
4
5
6
mcc1-01
mcc1-02
mcc1-03
mcc1-04
mcc1-05
8.00
16.00
24.00
32.00
40.00
2-THETA ANGLE (deg)

Appendix 1 - 2


Composite plot of the XRD data down core mcc1
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6
4
2
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mcc1-07
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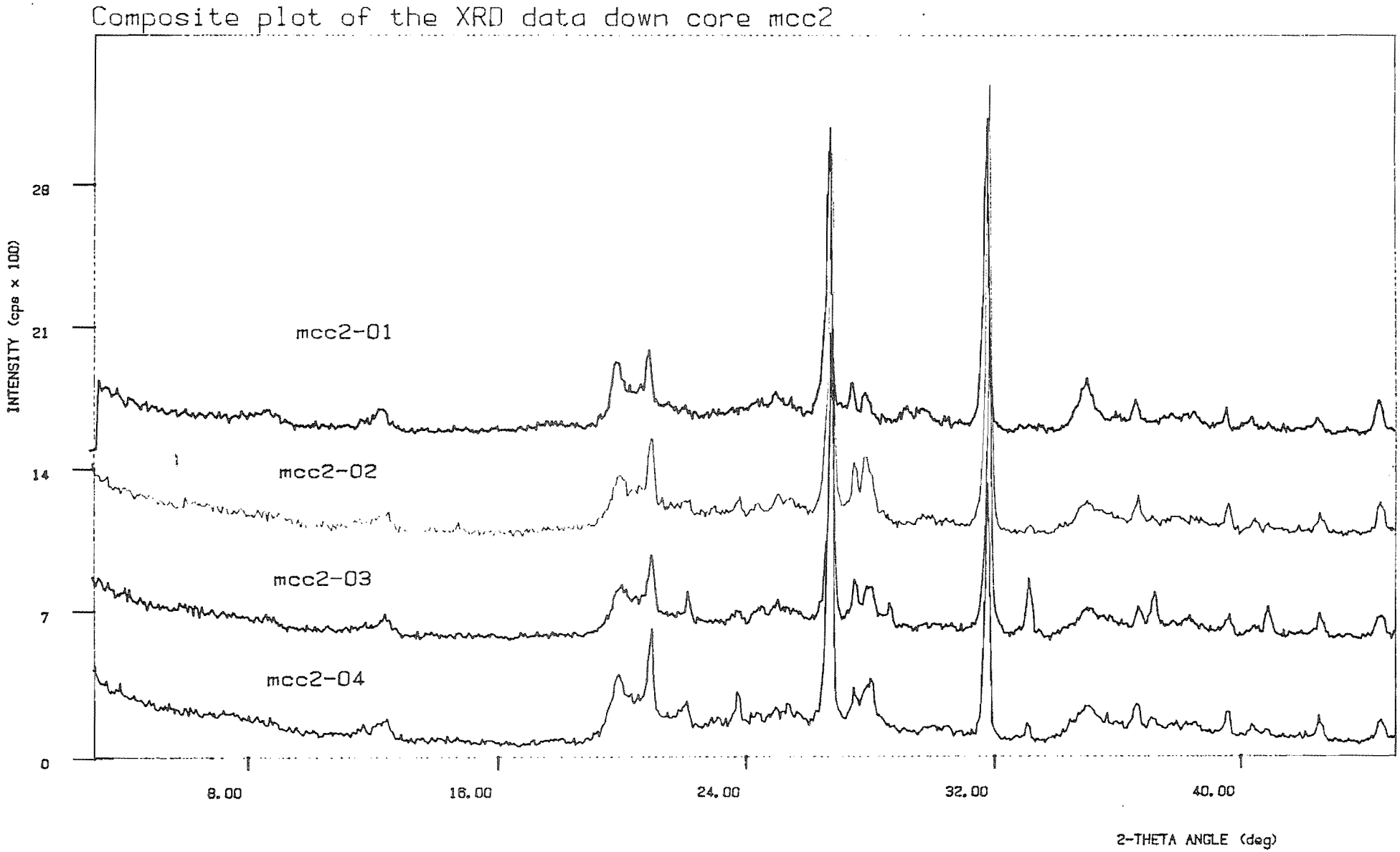
16.00
24.00
32.00
40.00
2-THETA ANGLE (deg)

Appendix 1 - 3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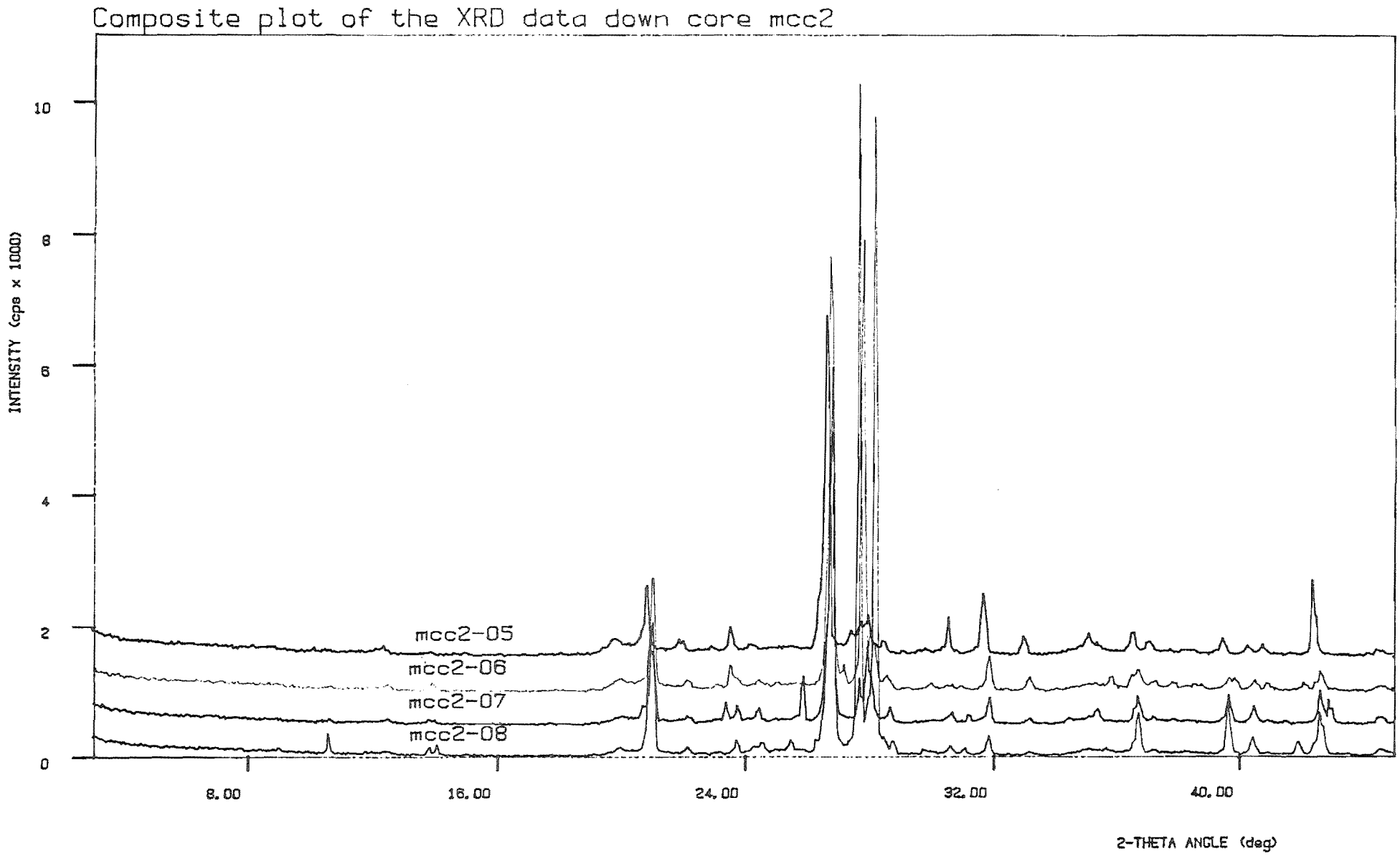
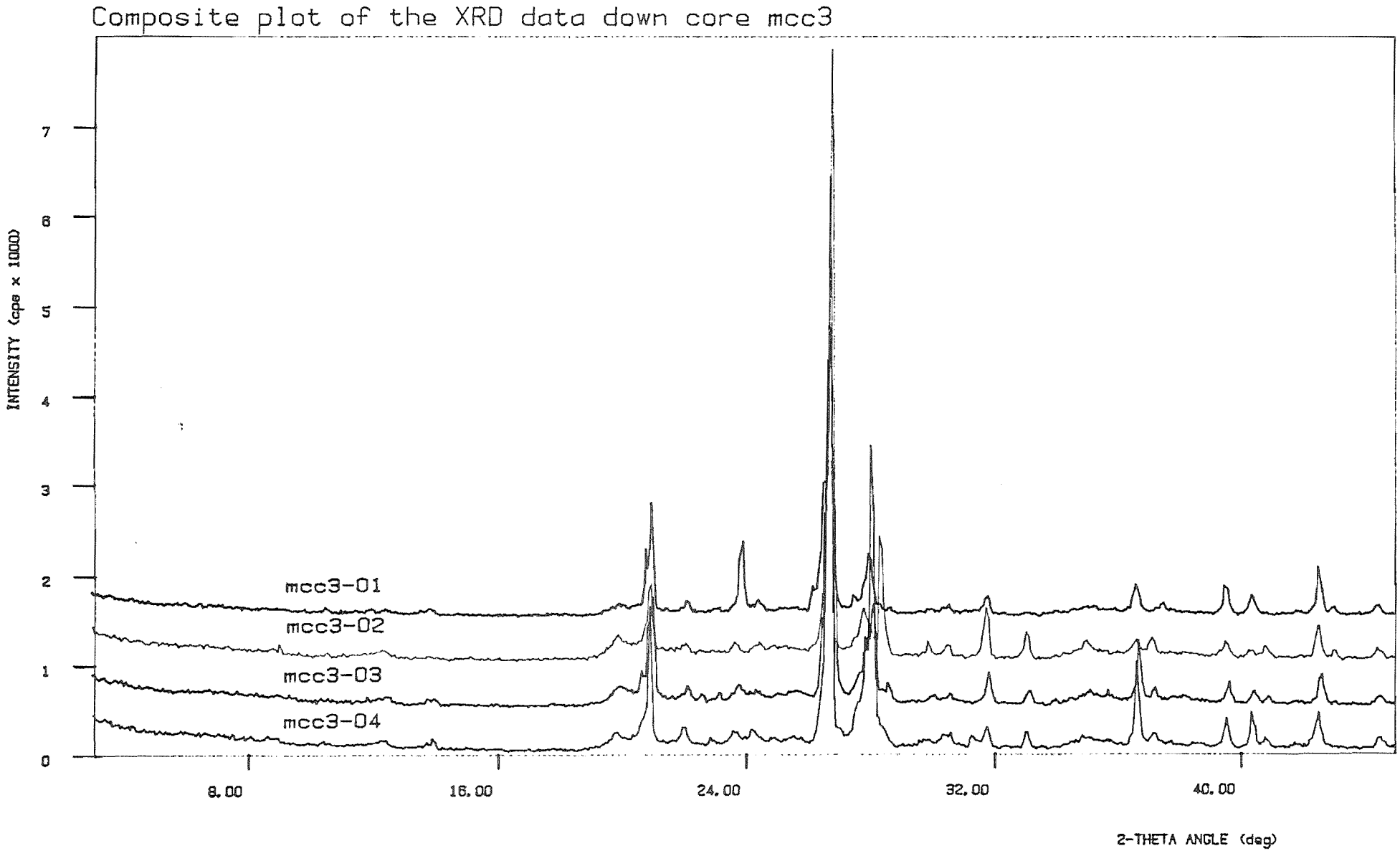
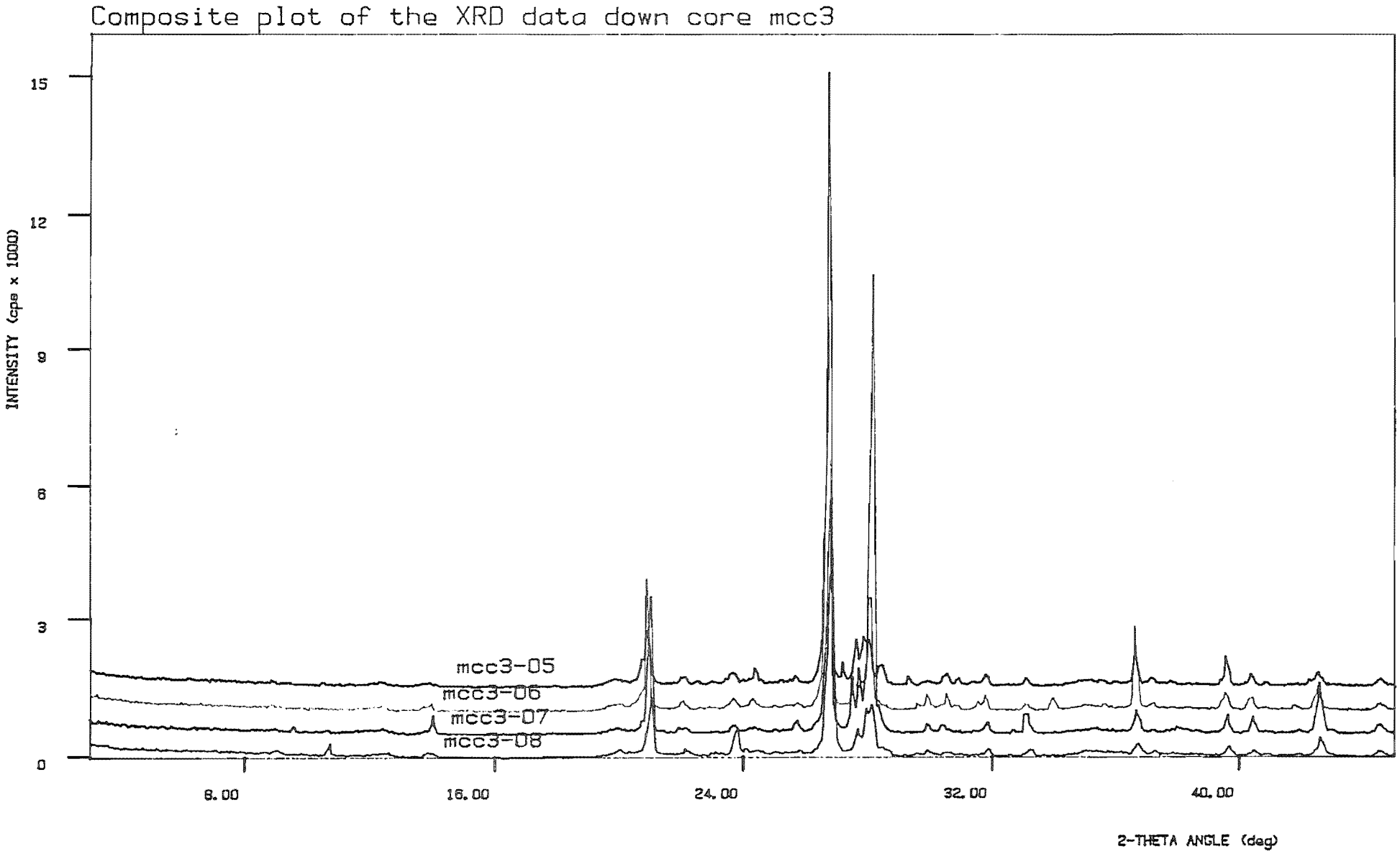
mcc2-03
mcc2-04
8.00
16.00
24.00
32.00
40.00
2-THETA ANGLE (deg)

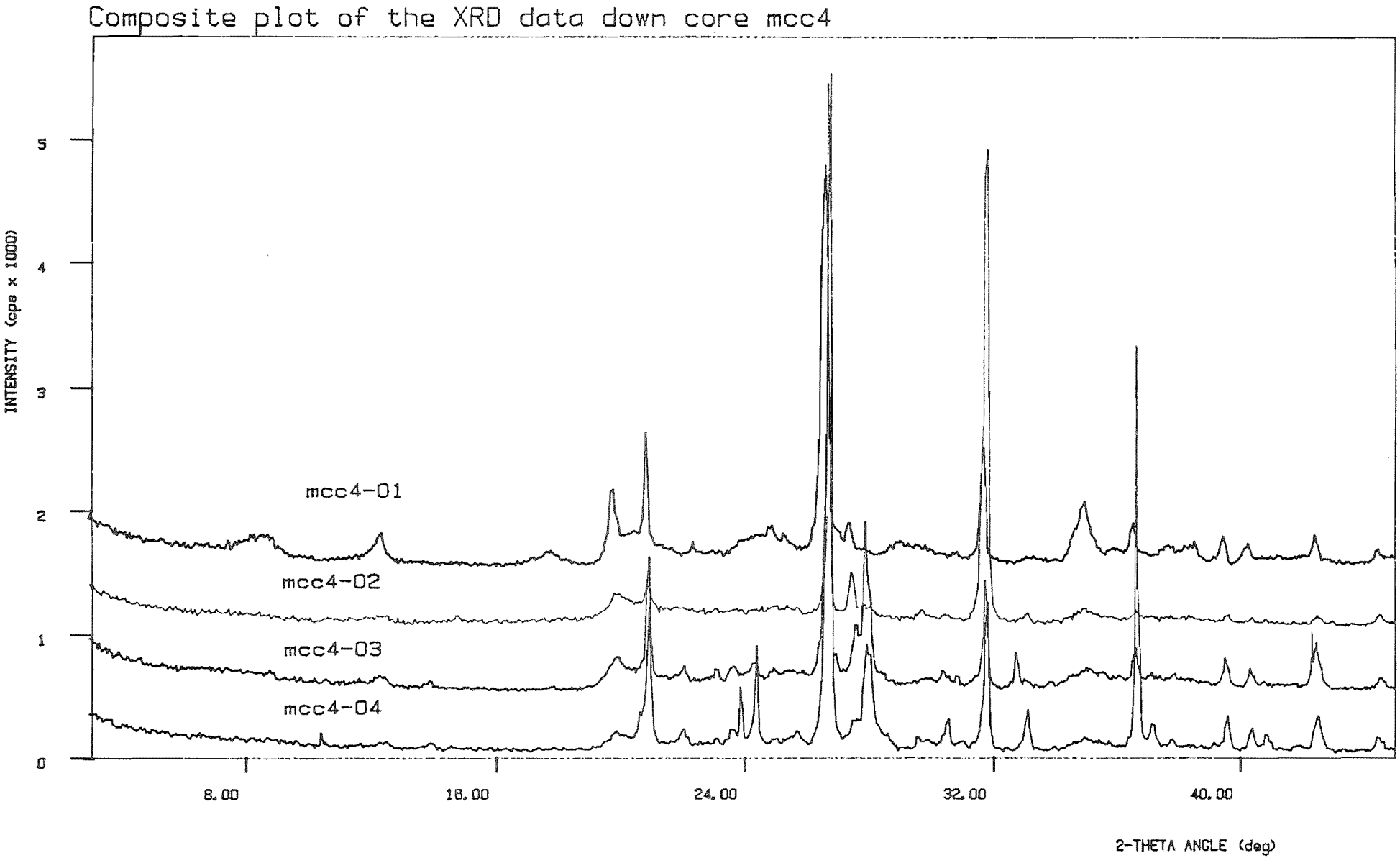

Composite plot of the XRD data down core mcc2
INTENSITY (cps x 1000)
10
8
6
4
2
0
mcc2-05
mcc2-06
mcc2-07
mcc2-08
8.00
16.00
24.00
32.00
40.00
2-THETA ANGLE (deg)

Appendix 1 - 5

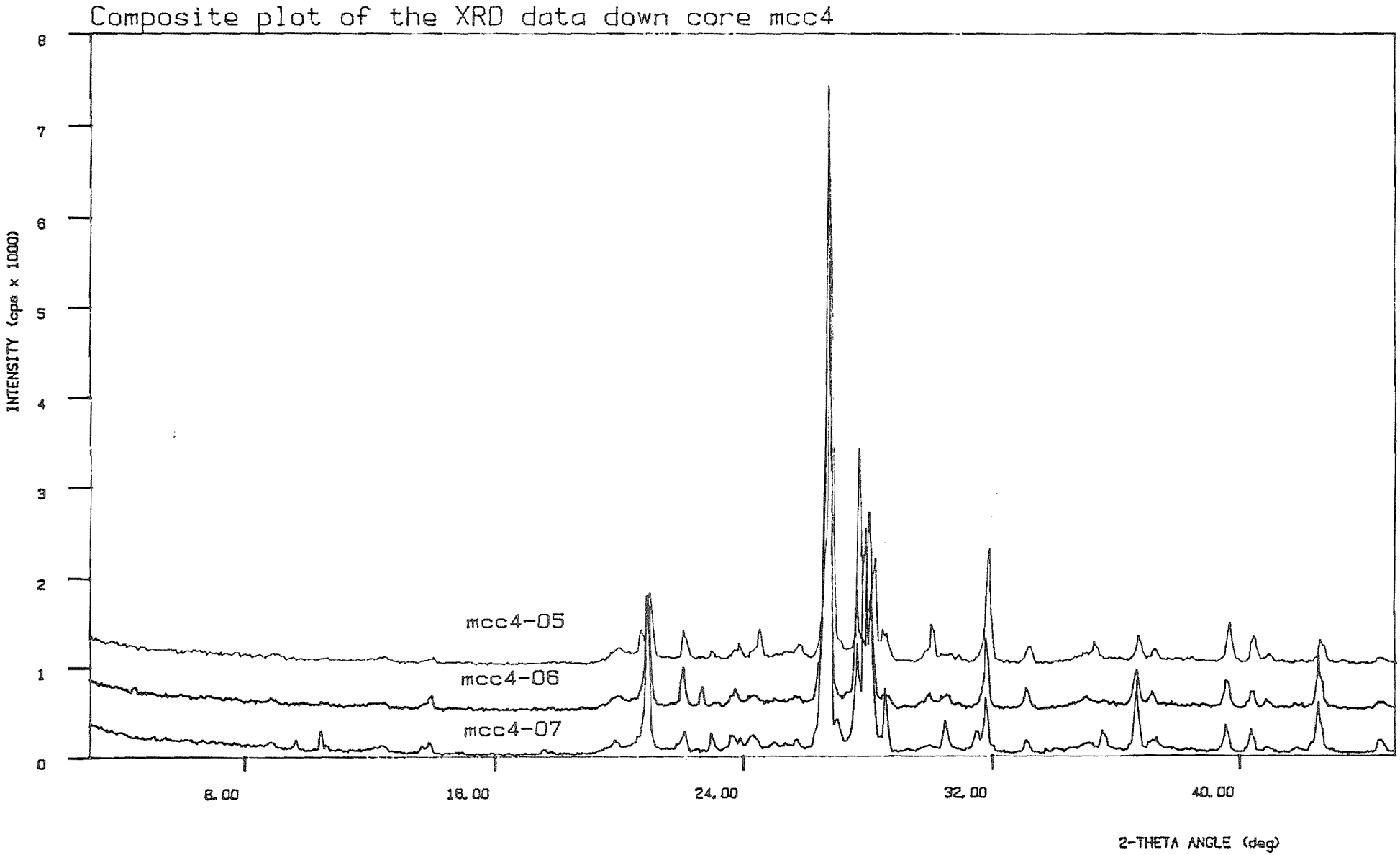

Composite plot of the XRD data down core mcc3
INTENSITY (cps x 1000)
0
1
2
3
4
5
6
7
mcc3-01
mcc3-02
mcc3-03
mcc3-04
8.00
16.00
24.00
32.00
40.00
2-THETA ANGLE (deg)

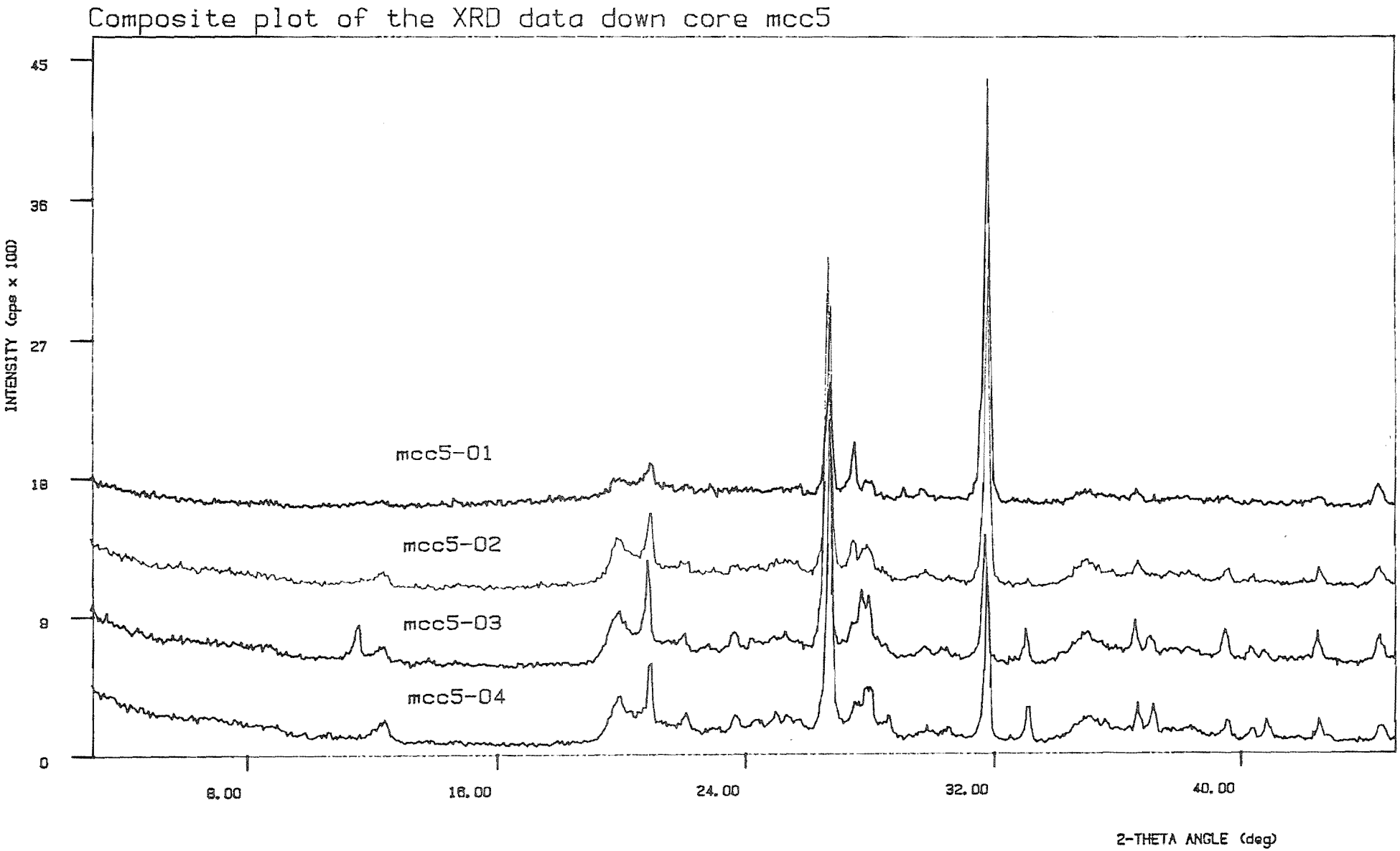

Composite plot of the XRD data down core mcc3
INTENSITY (cps x 1000)
15
12
9
6
3
0
mcc3-05
mcc3-06
mcc3-07
mcc3-08
8.00
16.00
24.00
32.00
40.00
2-THETA ANGLE (deg)

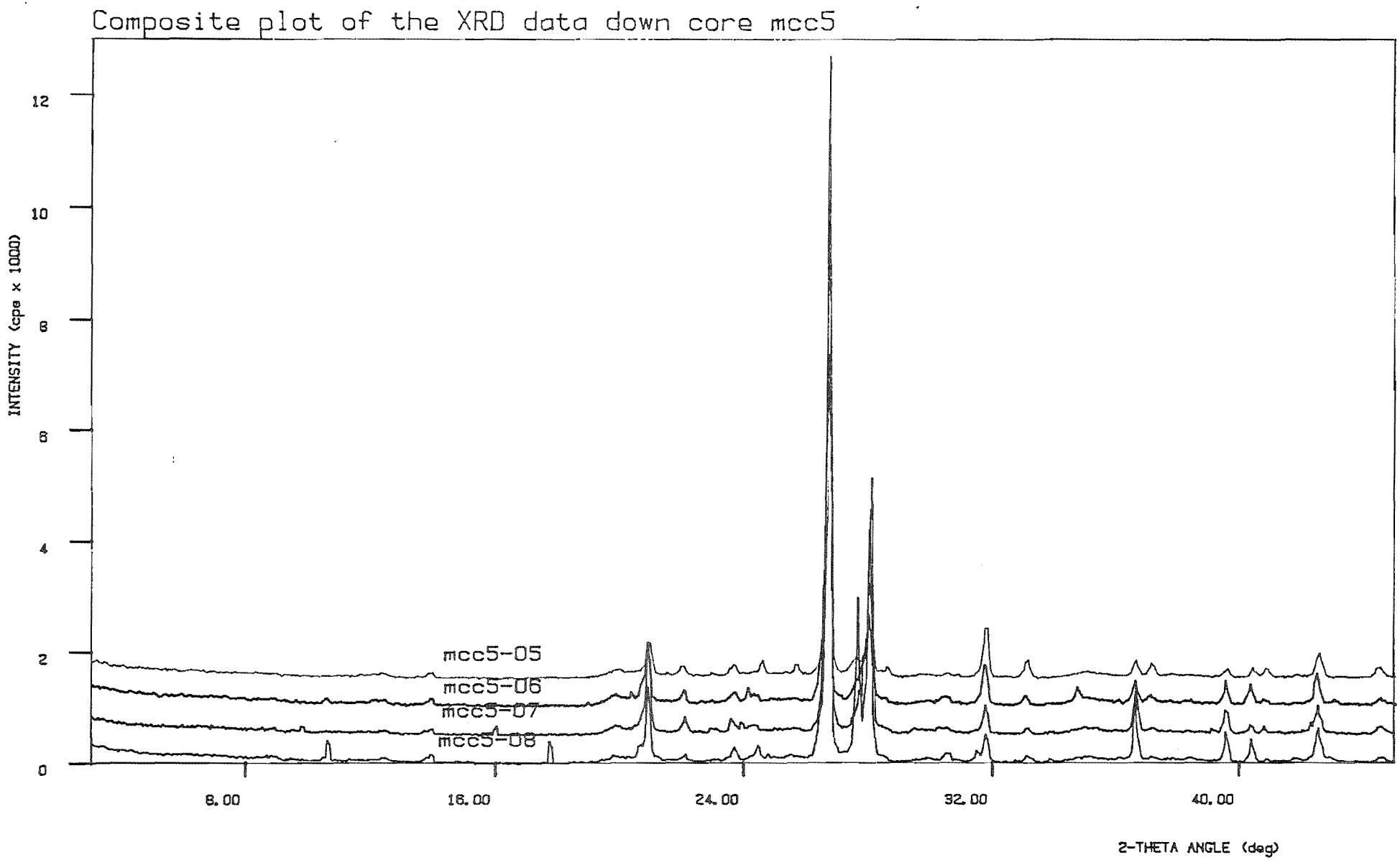
Appendix 1 - 7

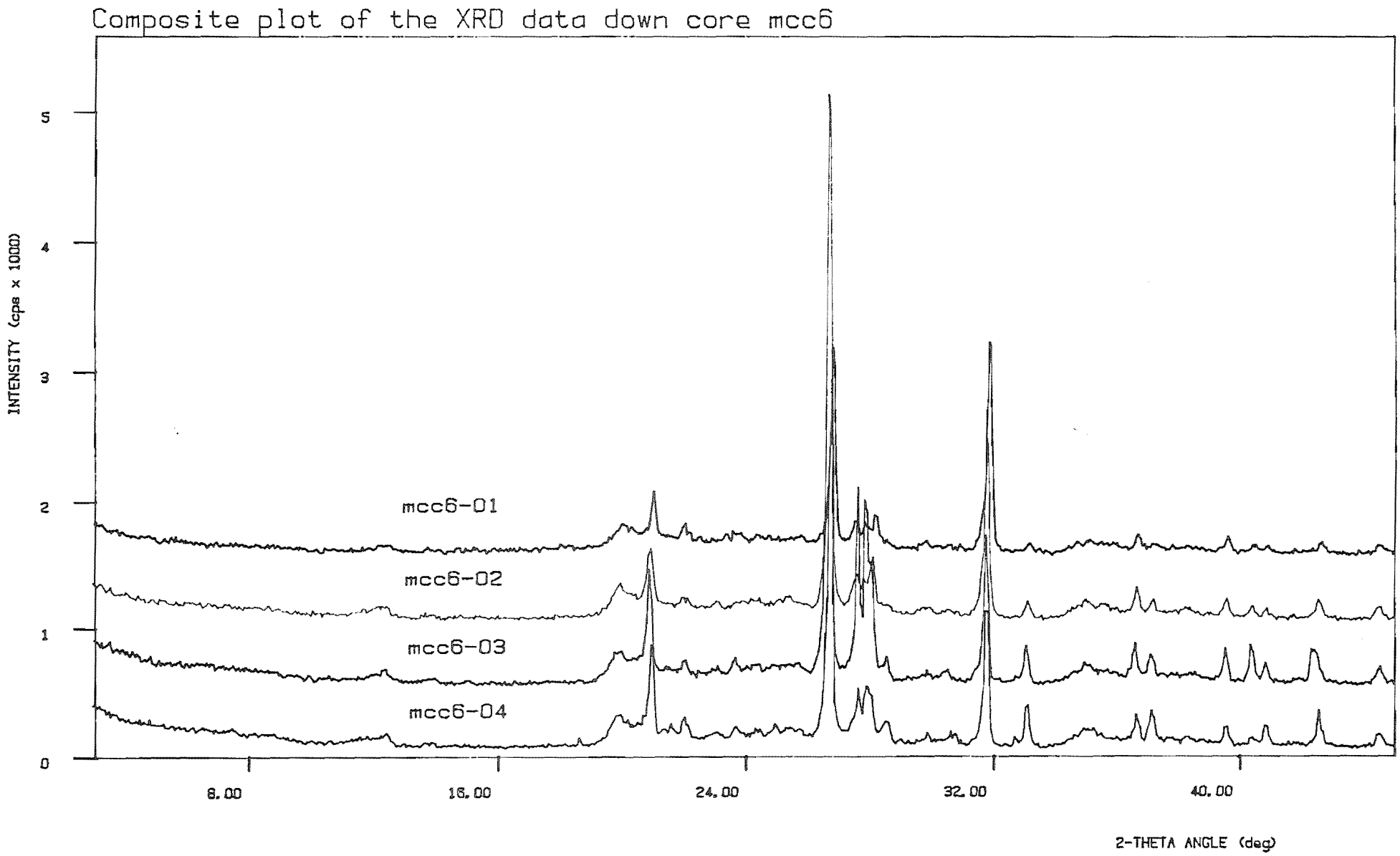

Composite plot of the XRD data down core mcc4
INTENSITY (cps x 1000)
0
1
2
3
4
5
mcc4-01
mcc4-02
mcc4-03
mcc4-04
8.00
16.00
24.00
32.00
40.00
2-THETA ANGLE (deg)

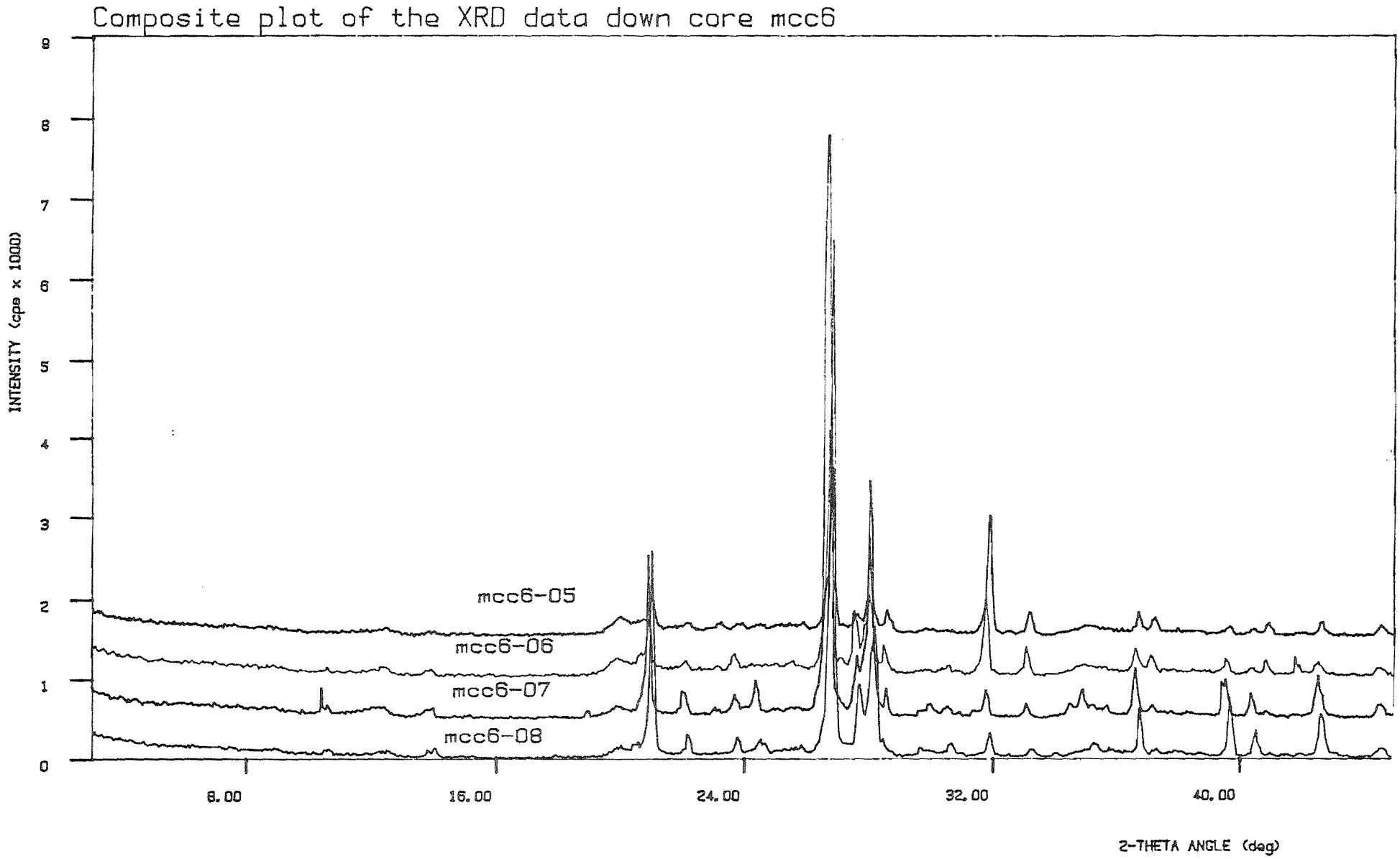
Appendix 1 - 8

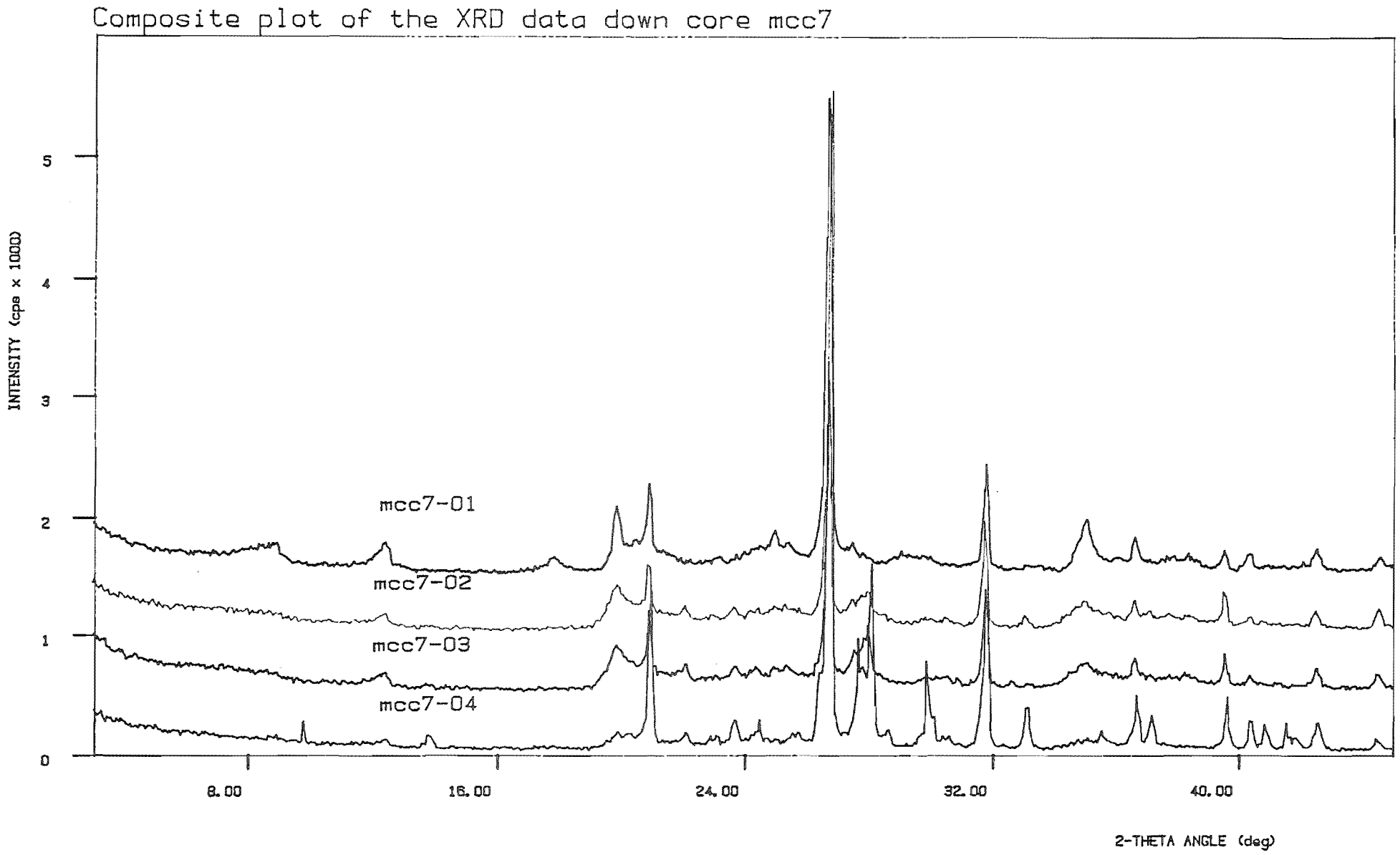

Composite plot of the XRD data down core mcc4
INTENSITY (cps x 1000)
0
1
2
3
4
5
6
7
8
mcc4-05
mcc4-06
mcc4-07
8.00
16.00
24.00
32.00
40.00
2-THETA ANGLE (deg)

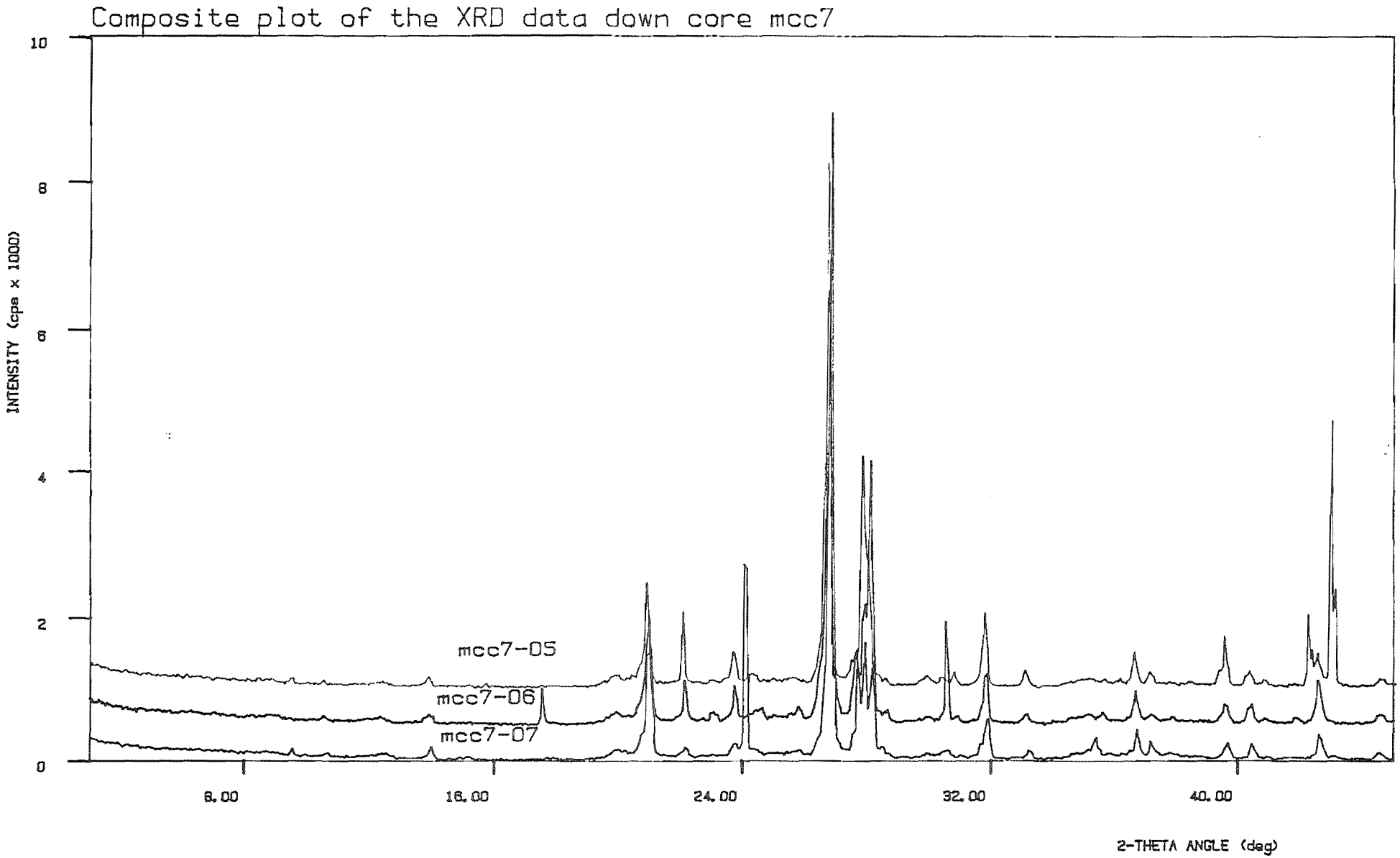

Composite plot of the XRD data down core mcc5
INTENSITY (cps x 100)
45
36
27
18
9
0
mcc5-01
mcc5-02
mcc5-03
mcc5-04
8.00
16.00
24.00
32.00
40.00
2-THETA ANGLE (deg)

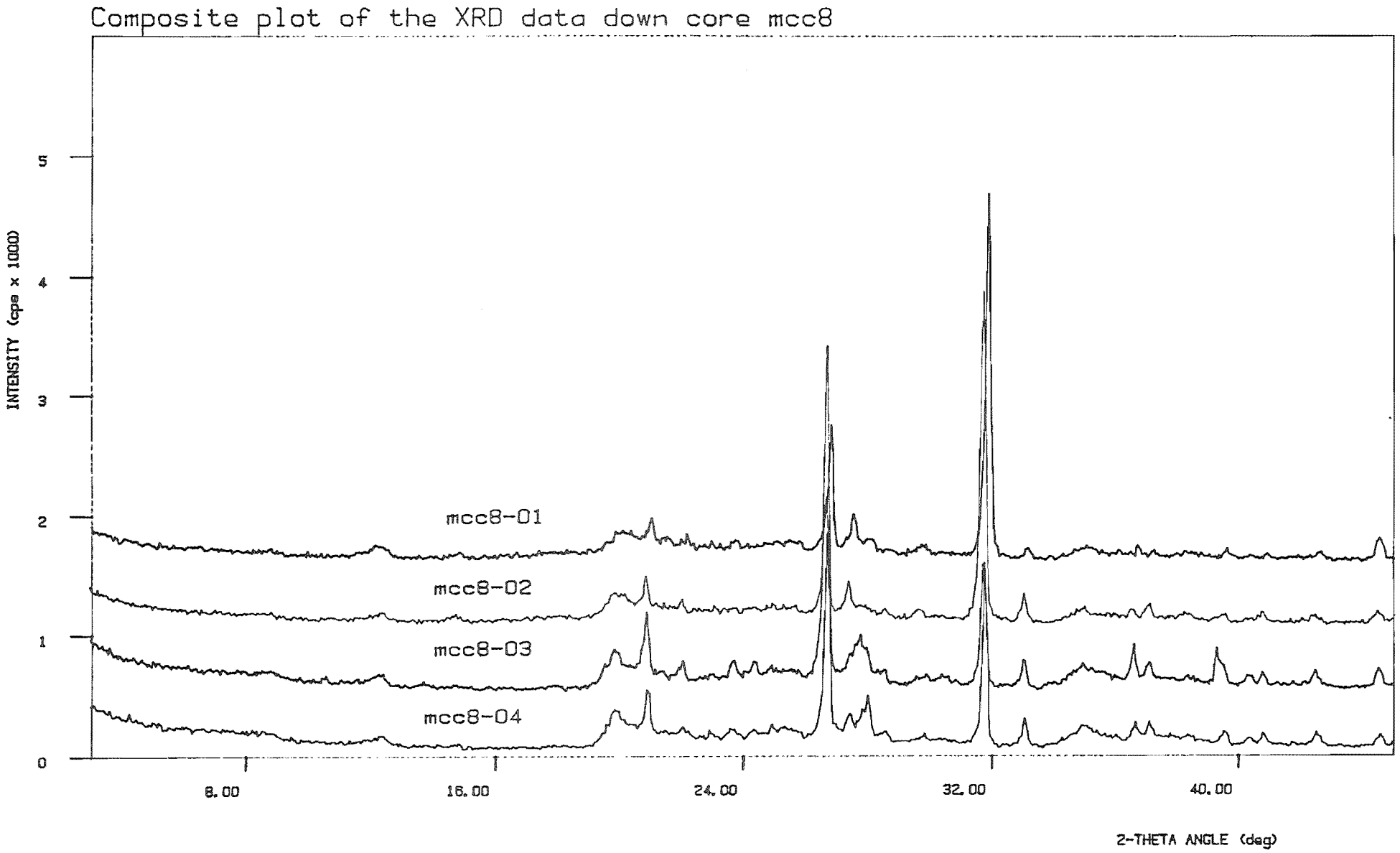

Composite plot of the XRD data down core mcc5
INTENSITY (cps x 1000)
12
10
8
6
4
2
0
mcc5-05
mcc5-06
mcc5-07
mcc5-08
8.00
16.00
24.00
32.00
40.00
2-THETA ANGLE (deg)

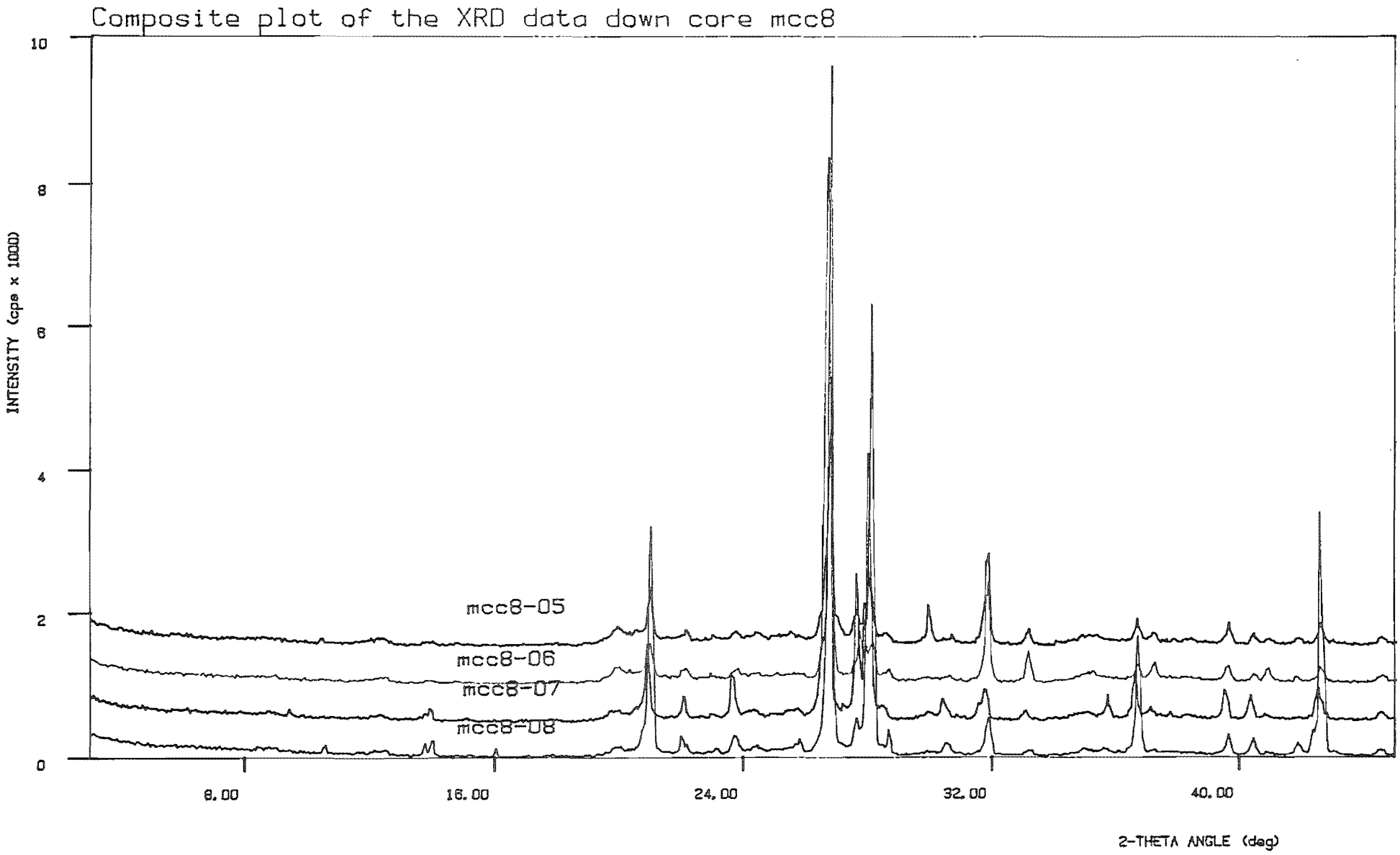

Composite plot of the XRD data down core mcc6
INTENSITY (cps x 1000)
0
1
2
3
4
5
mcc6-01
mcc6-02
mcc6-03
mcc6-04
8.00
16.00
24.00
32.00
40.00
2-THETA ANGLE (deg)

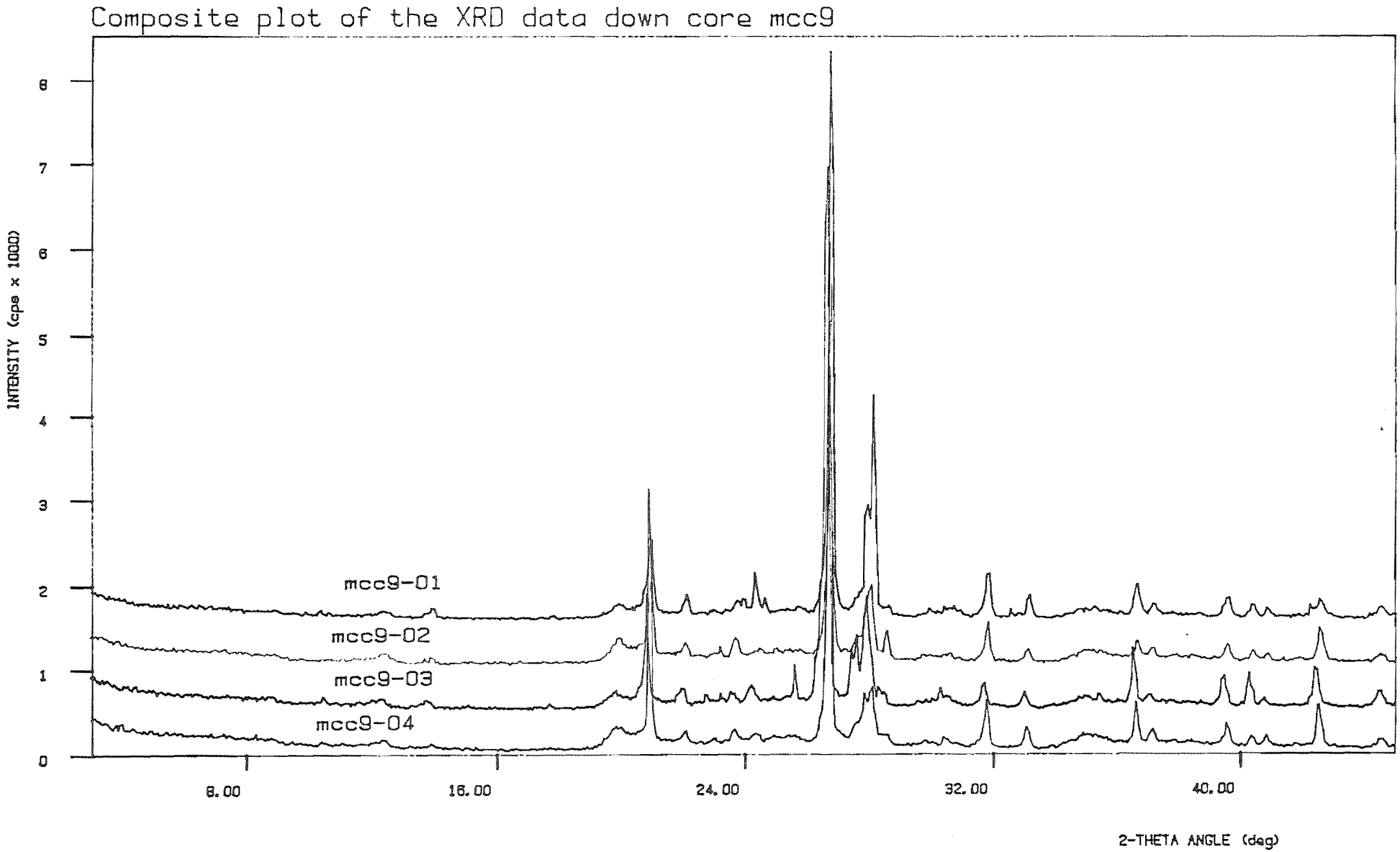

Composite plot of the XRD data down core mcc6
INTENSITY (cps x 1000)
9
8
7
6
5
4
3
2
1
0
mcc6-05
mcc6-06
mcc6-07
mcc6-08
8.00
16.00
24.00
32.00
40.00
2-THETA ANGLE (deg)

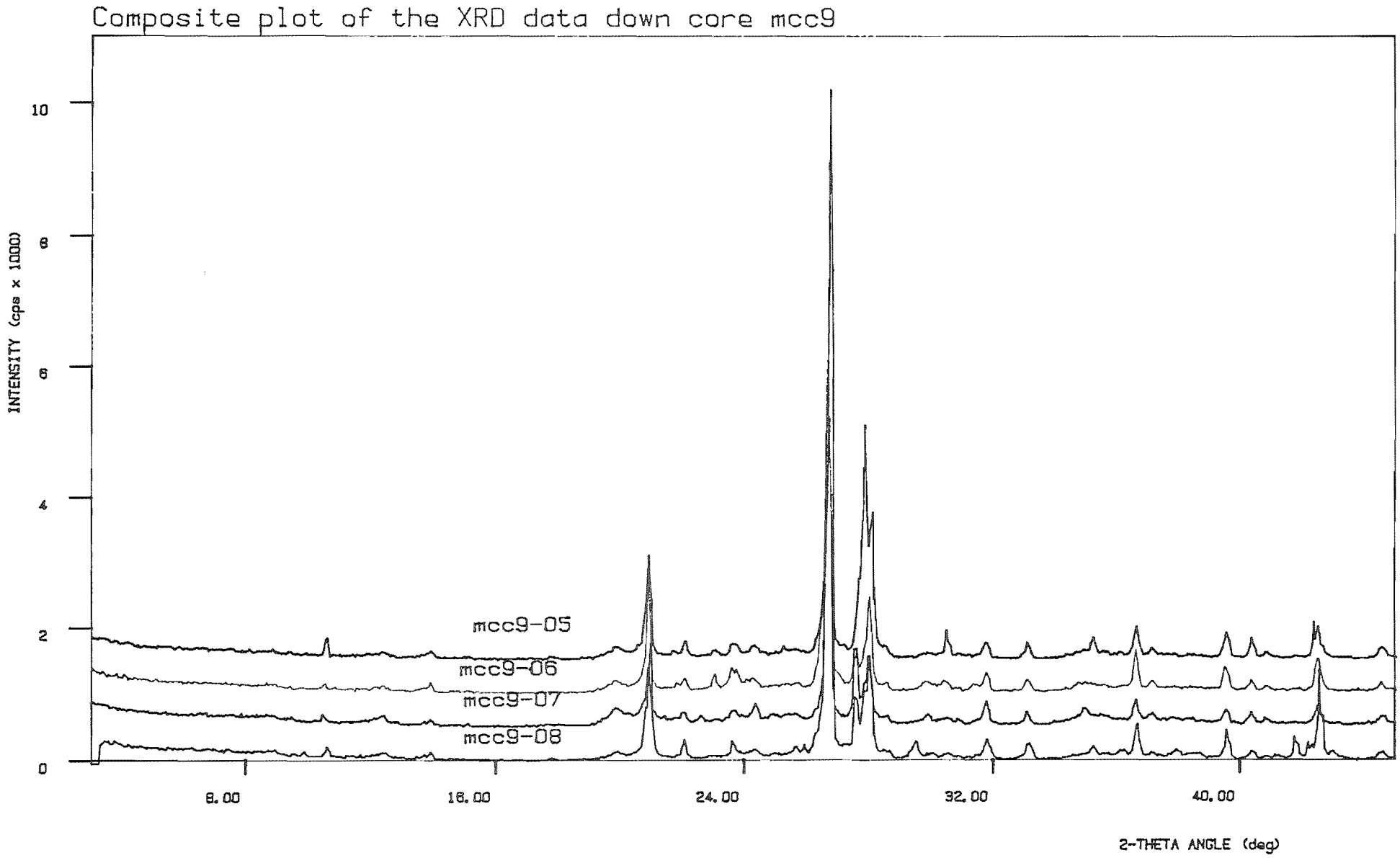

Composite plot of the XRD data down core mcc7
INTENSITY (cps x 1000)
0
1
2
3
4
5
mcc7-01
mcc7-02
mcc7-03
mcc7-04
8.00
16.00
24.00
32.00
40.00
2-THETA ANGLE (deg)

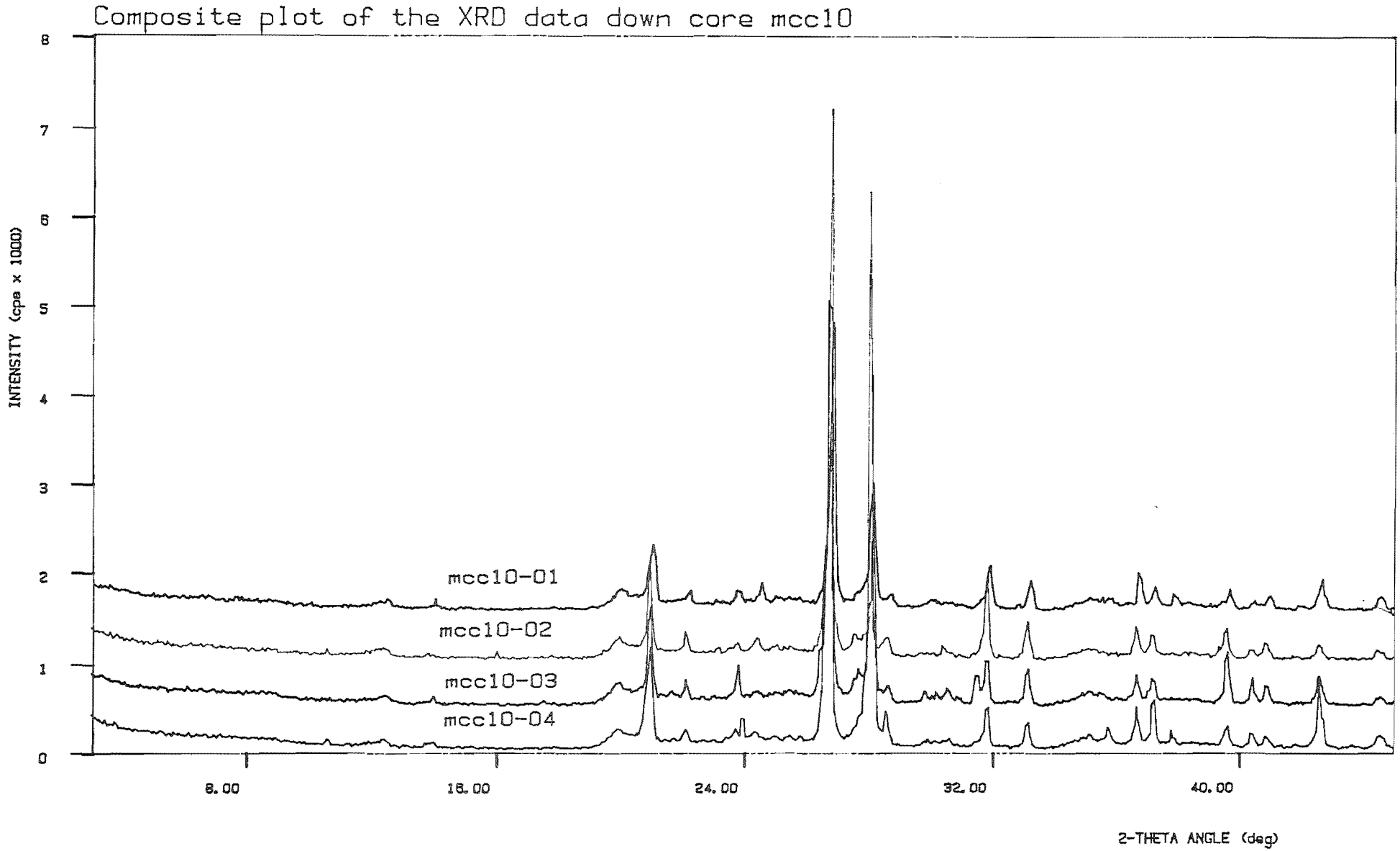

Composite plot of the XRD data down core mcc7
INTENSITY (cps x 1000)
10
8
6
4
2
0
mcc7-05
mcc7-06
mcc7-07
8.00
16.00
24.00
32.00
40.00
2-THETA ANGLE (deg)

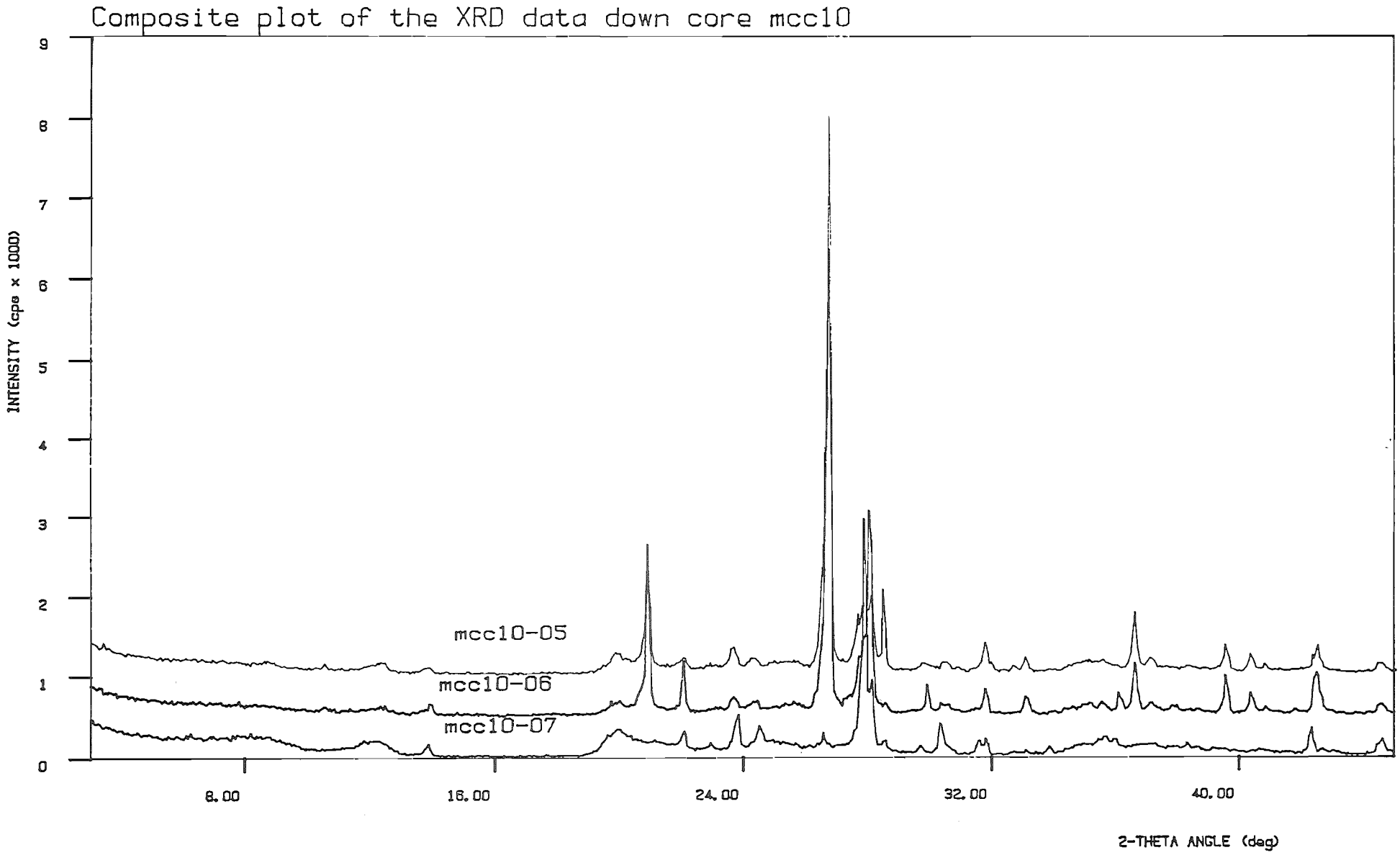

Composite plot of the XRD data down core mcc8
INTENSITY (cps x 1000)
0
1
2
3
4
5
mcc8-01
mcc8-02
mcc8-03
mcc8-04
8.00
16.00
24.00
32.00
40.00
2-THETA ANGLE (deg)

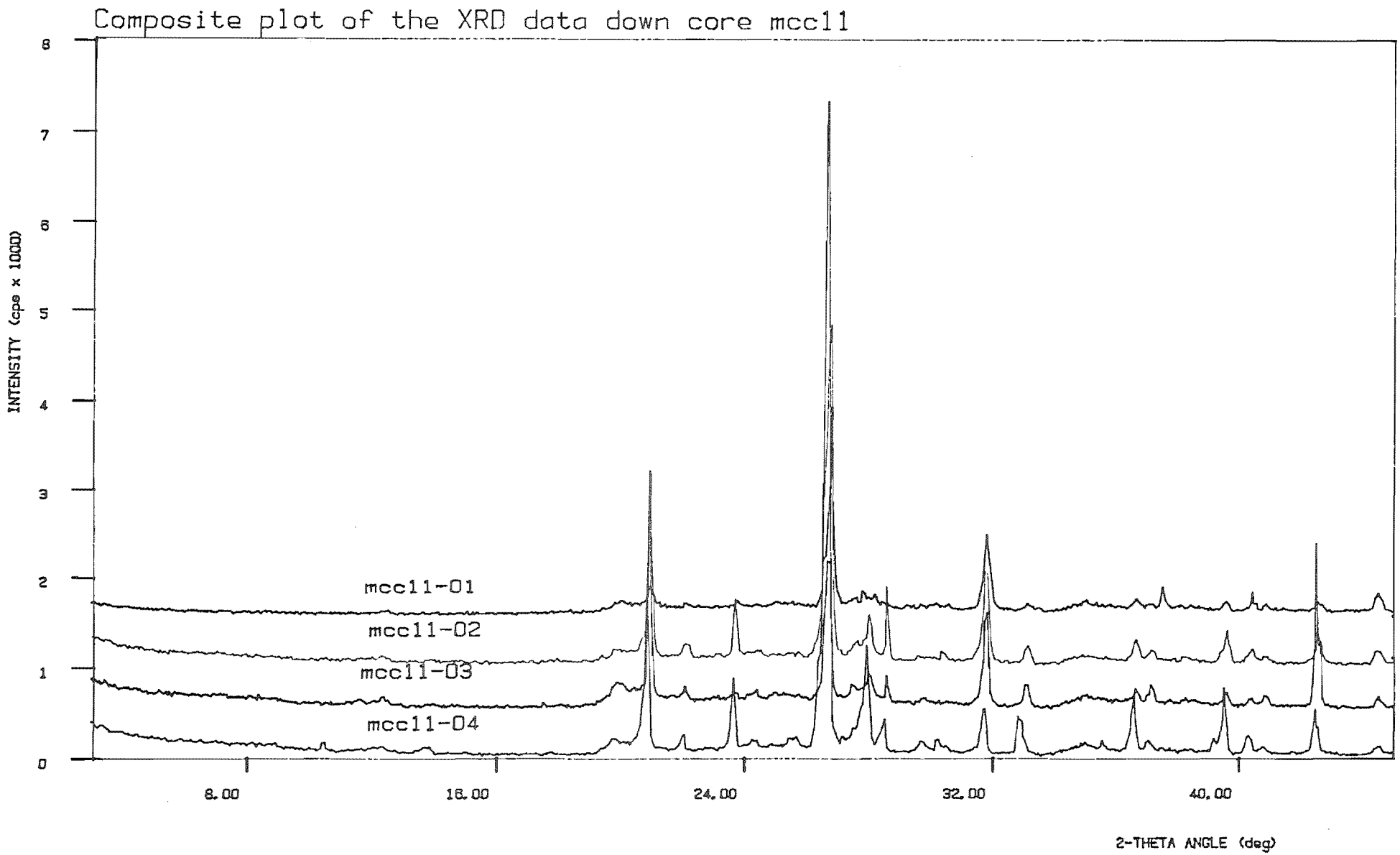

Composite plot of the XRD data down core mcc8
INTENSITY (cps x 1000)
10
8
6
4
2
0
mcc8-05
mcc8-06
mcc8-07
mcc8-08
8.00
16.00
24.00
32.00
40.00
2-THETA ANGLE (deg)

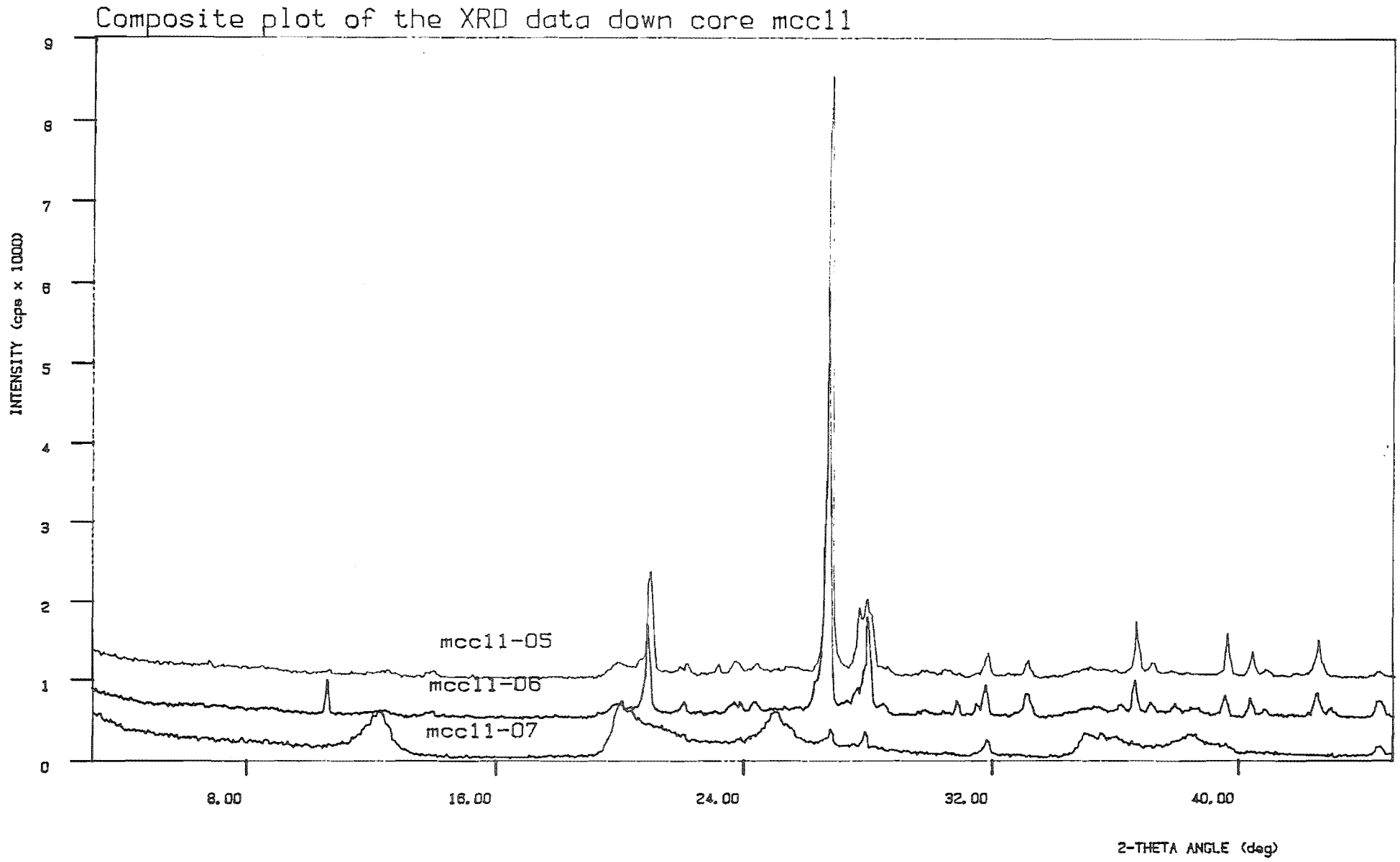

Composite plot of the XRD data down core mcc9
INTENSITY (cps x 1000)
0
1
2
3
4
5
6
7
8
mcc9-01
mcc9-02
mcc9-03
mcc9-04
8.00
16.00
24.00
32.00
40.00
2-THETA ANGLE (deg)

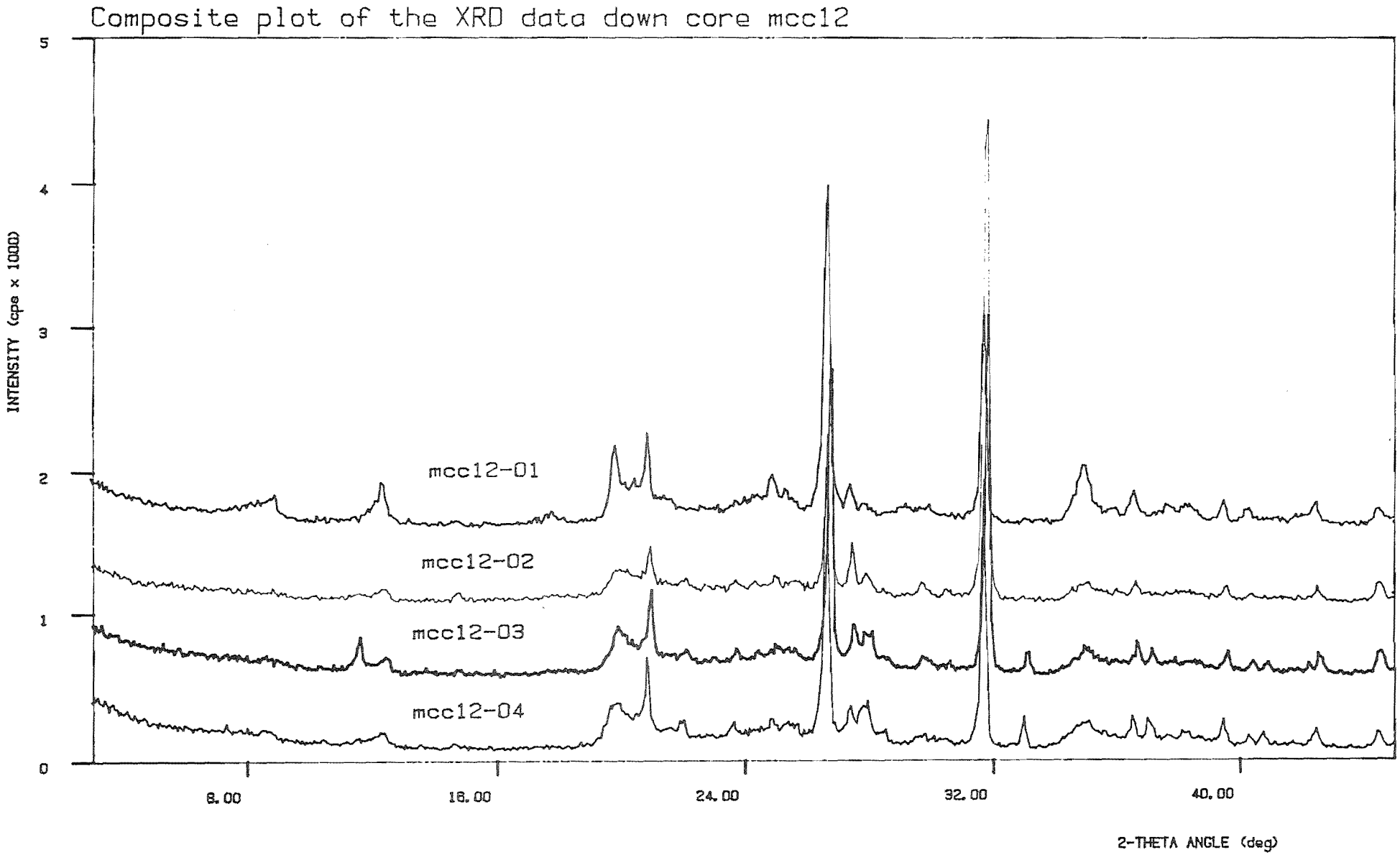

Composite plot of the XRD data down core mcc9
INTENSITY (cps x 1000)
10
8
6
4
2
0
mcc9-05
mcc9-06
mcc9-07
mcc9-08
8.00
16.00
24.00
32.00
40.00
2-THETA ANGLE (deg)

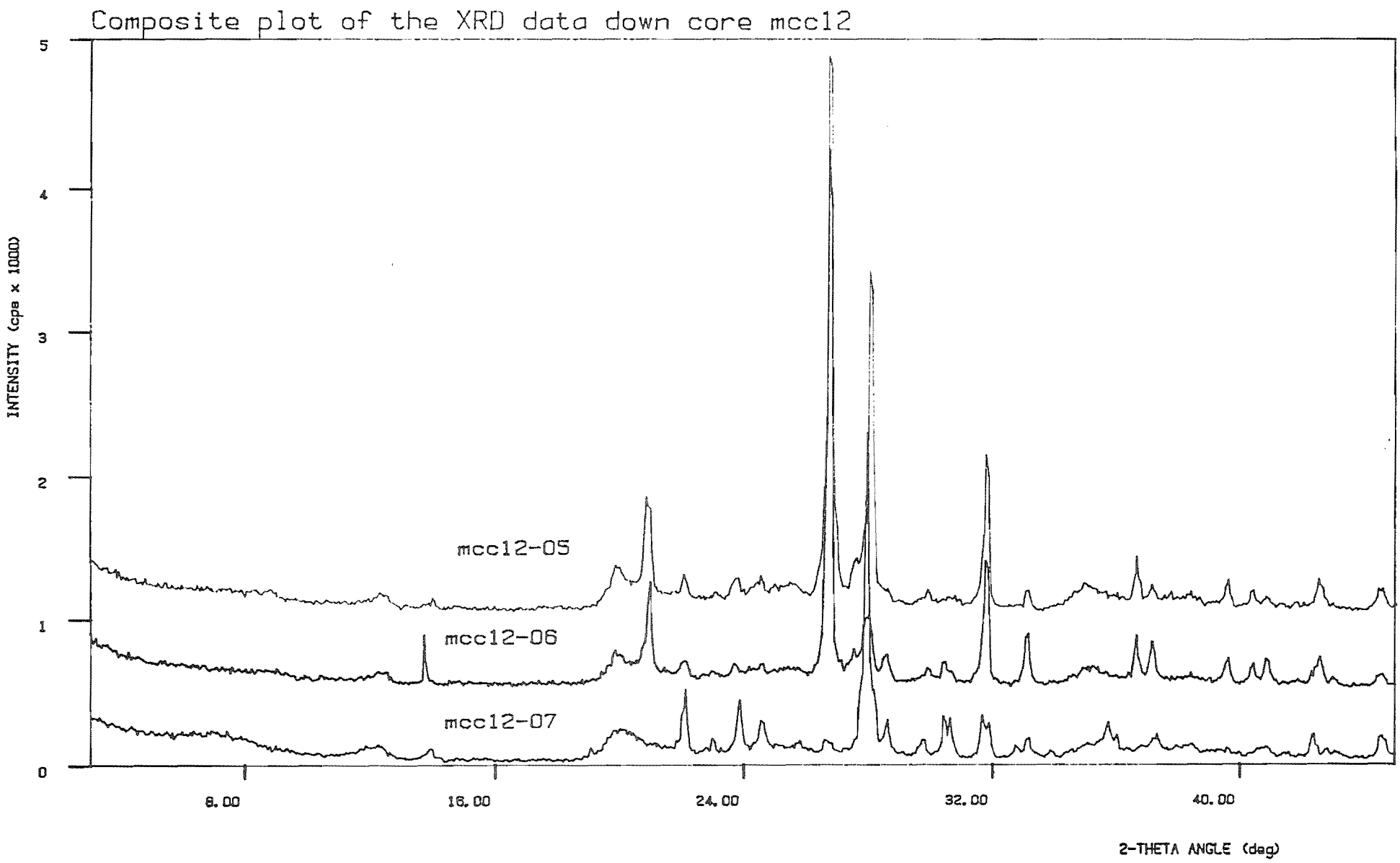

Composite plot of the XRD data down core mcc10
INTENSITY (cps x 1000)
0
1
2
3
4
5
6
7
8
mcc10-01
mcc10-02
mcc10-03
mcc10-04
8.00
16.00
24.00
32.00
40.00
2-THETA ANGLE (deg)

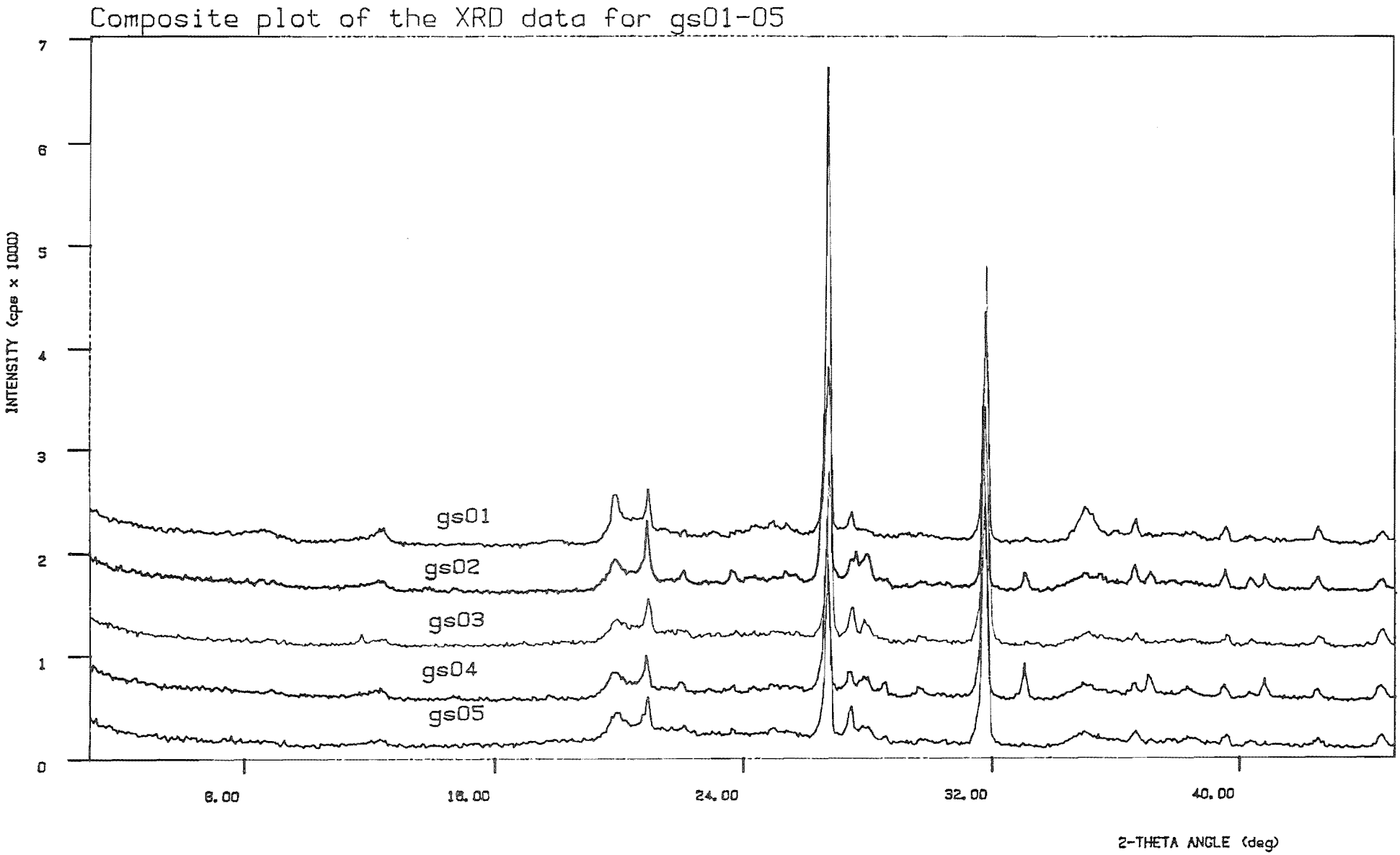

Composite plot of the XRD data down core mcc10
INTENSITY (cps x 1000)
0
1
2
3
4
5
6
7
8
9
mcc10-05
mcc10-06
mcc10-07
8.00
16.00
24.00
32.00
40.00
2-THETA ANGLE (deg)

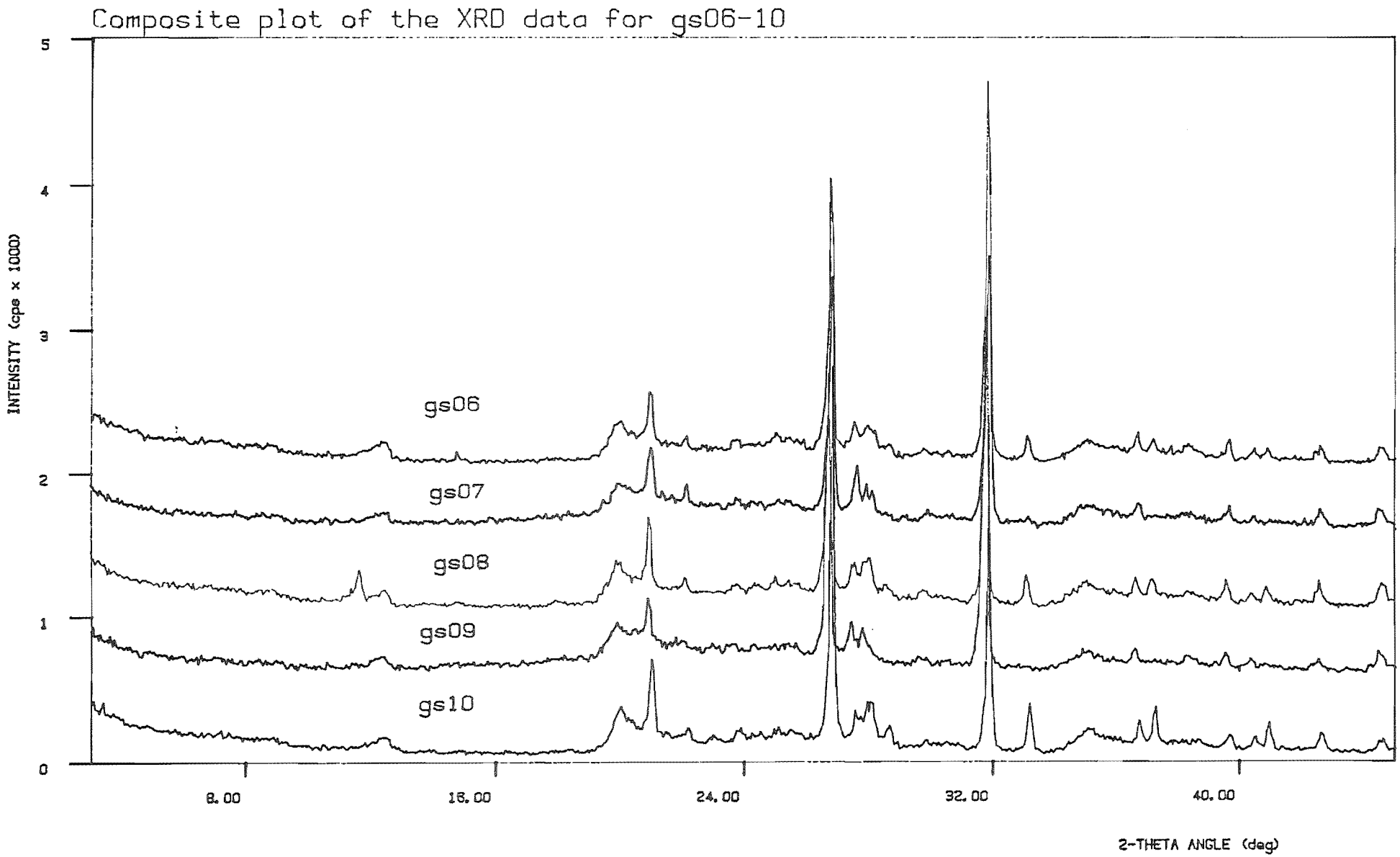

Composite plot of the XRD data down core mcc11
INTENSITY (cps x 1000)
0
1
2
3
4
5
6
7
8
mcc11-01
mcc11-02
mcc11-03
mcc11-04
8.00
16.00
24.00
32.00
40.00
2-THETA ANGLE (deg)

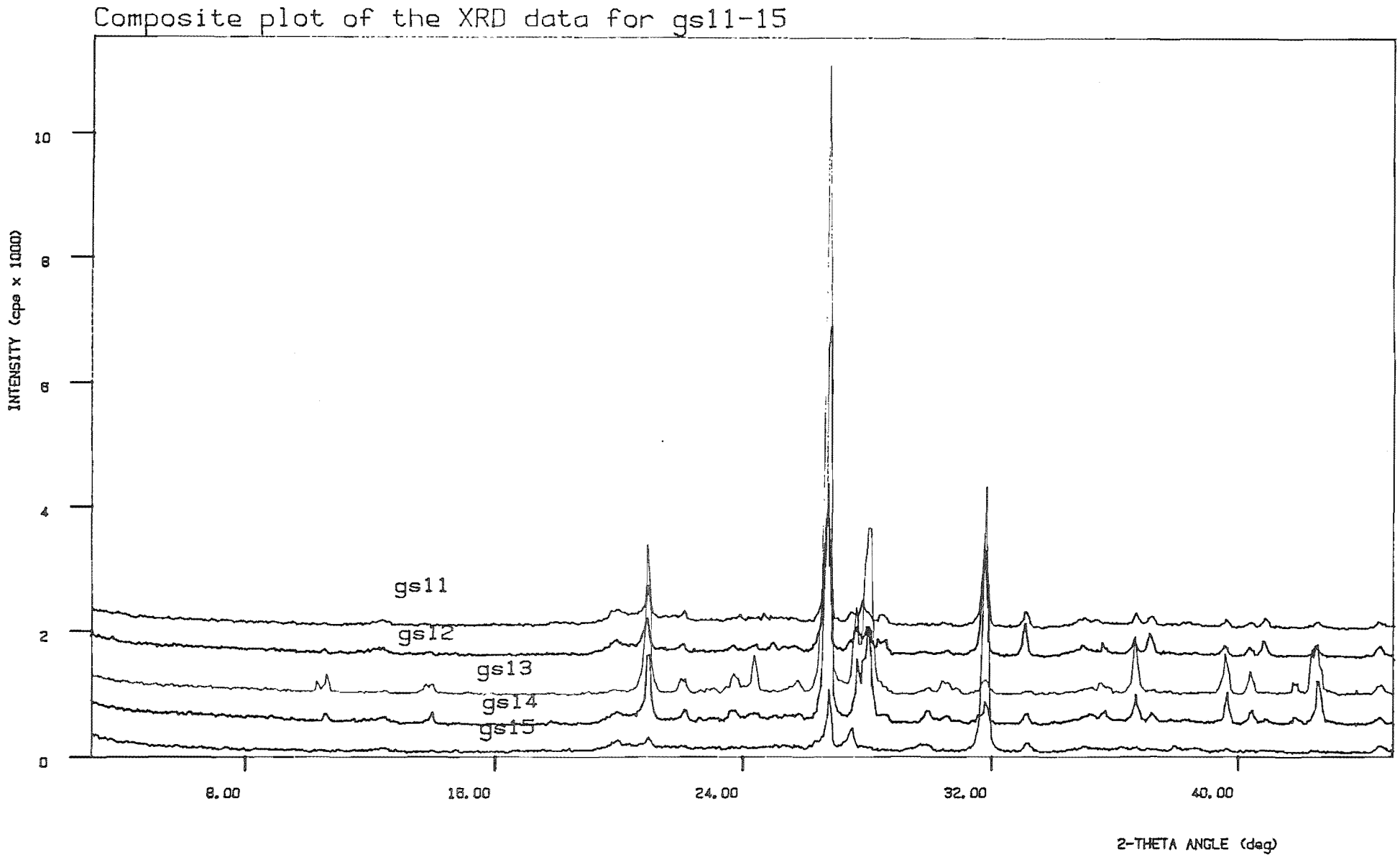

Composite plot of the XRD data down core mcc11
INTENSITY (cps x 1000)
9
8
7
6
5
4
3
2
1
0
mcc11-05
mcc11-06
mcc11-07
8.00
16.00
24.00
32.00
40.00
2-THETA ANGLE (deg)

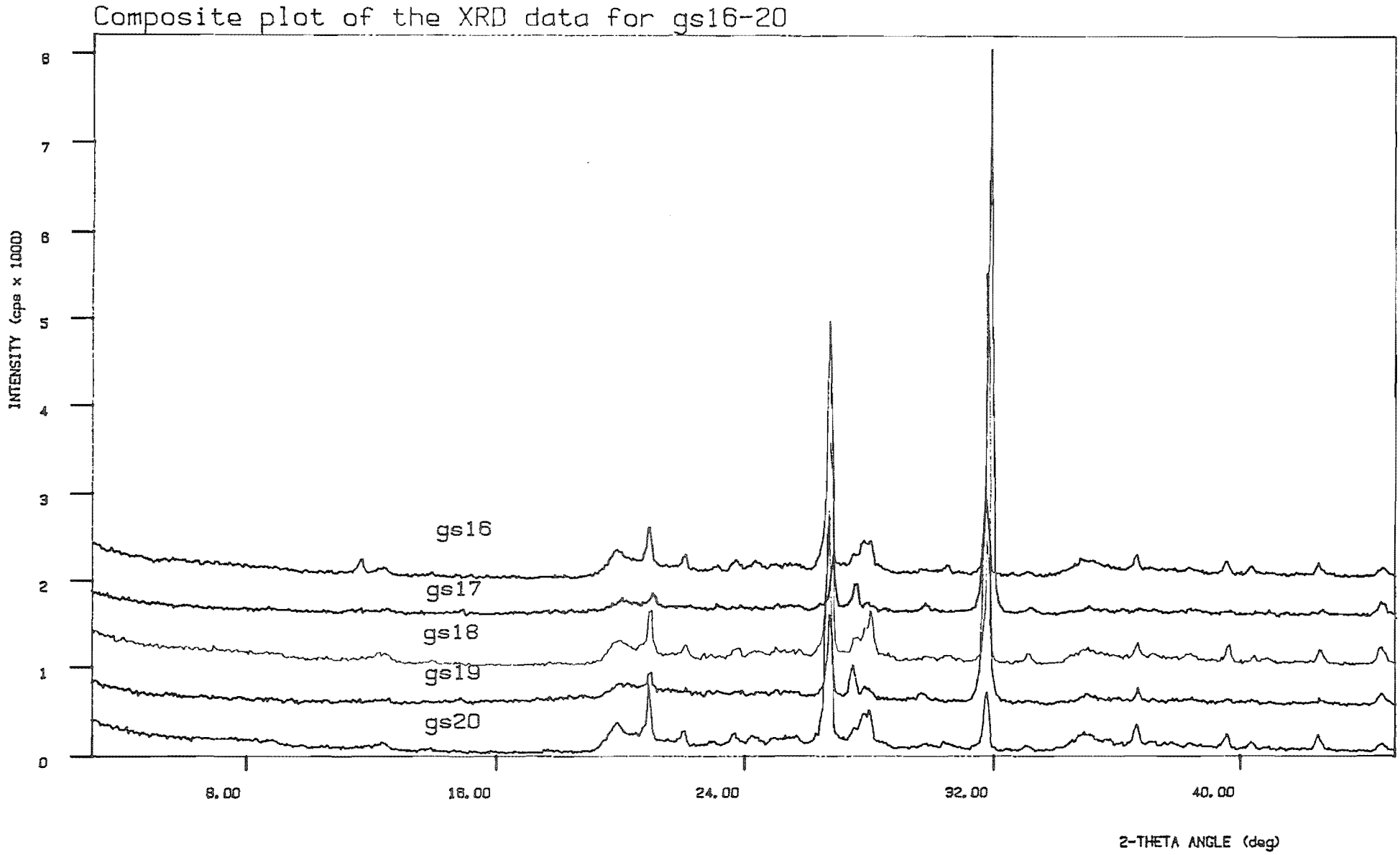

Composite plot of the XRD data down core mcc12
INTENSITY (cps x 1000)
5
4
3
2
1
0
mcc12-01
mcc12-02
mcc12-03
mcc12-04
8.00
16.00
24.00
32.00
40.00
2-THETA ANGLE (deg)

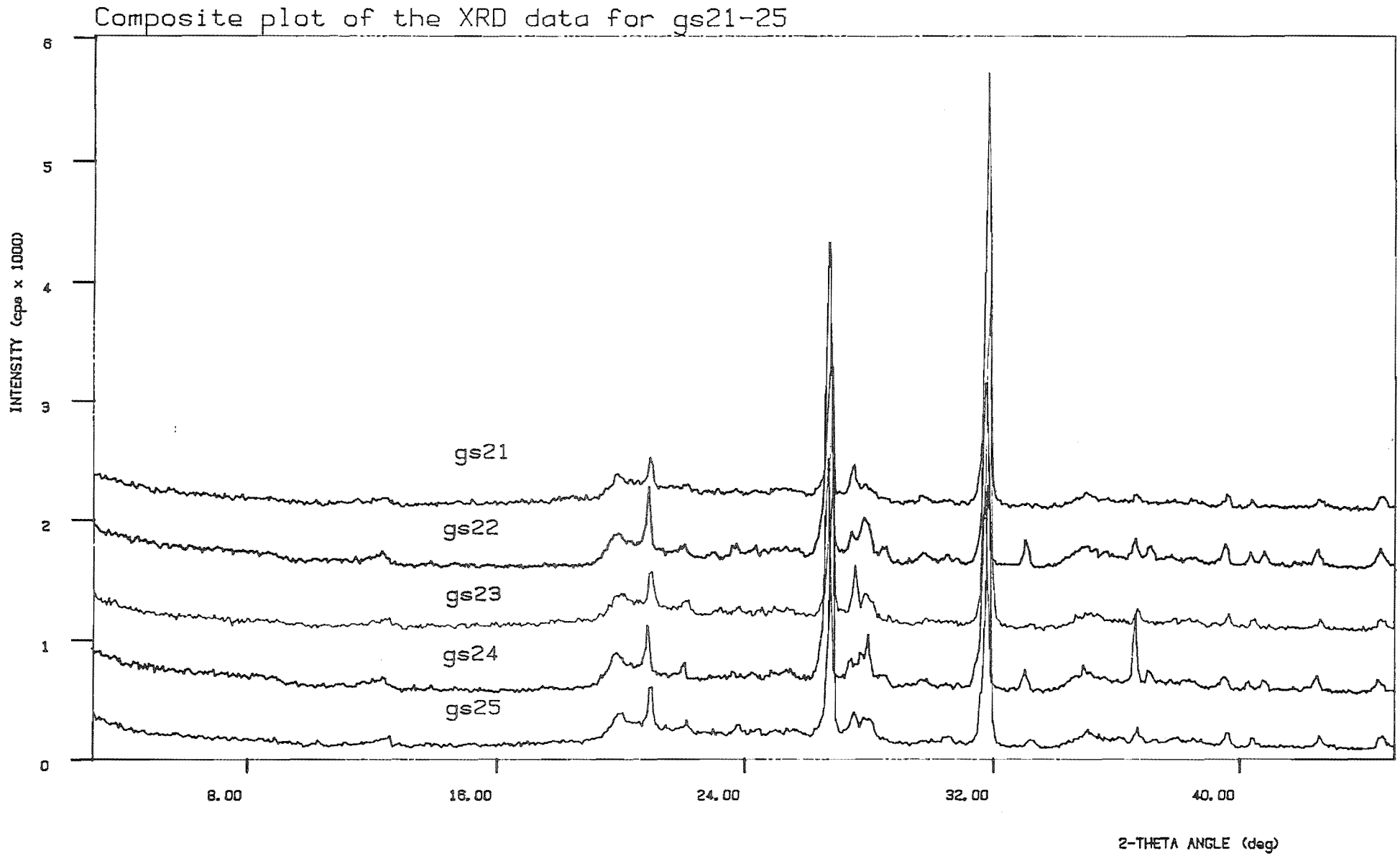

Composite plot of the XRD data down core mcc12
INTENSITY (cps x 1000)
5
4
3
2
1
0
mcc12-05
mcc12-06
mcc12-07
8.00
16.00
24.00
32.00
40.00
2-THETA ANGLE (deg)


Composite plot of the XRD data for gs01-05
INTENSITY (cps x 1000)
7
6
5
4
3
2
1
0
gs01
gs02
gs03
gs04
gs05
8.00
16.00
24.00
32.00
40.00
2-THETA ANGLE (deg)

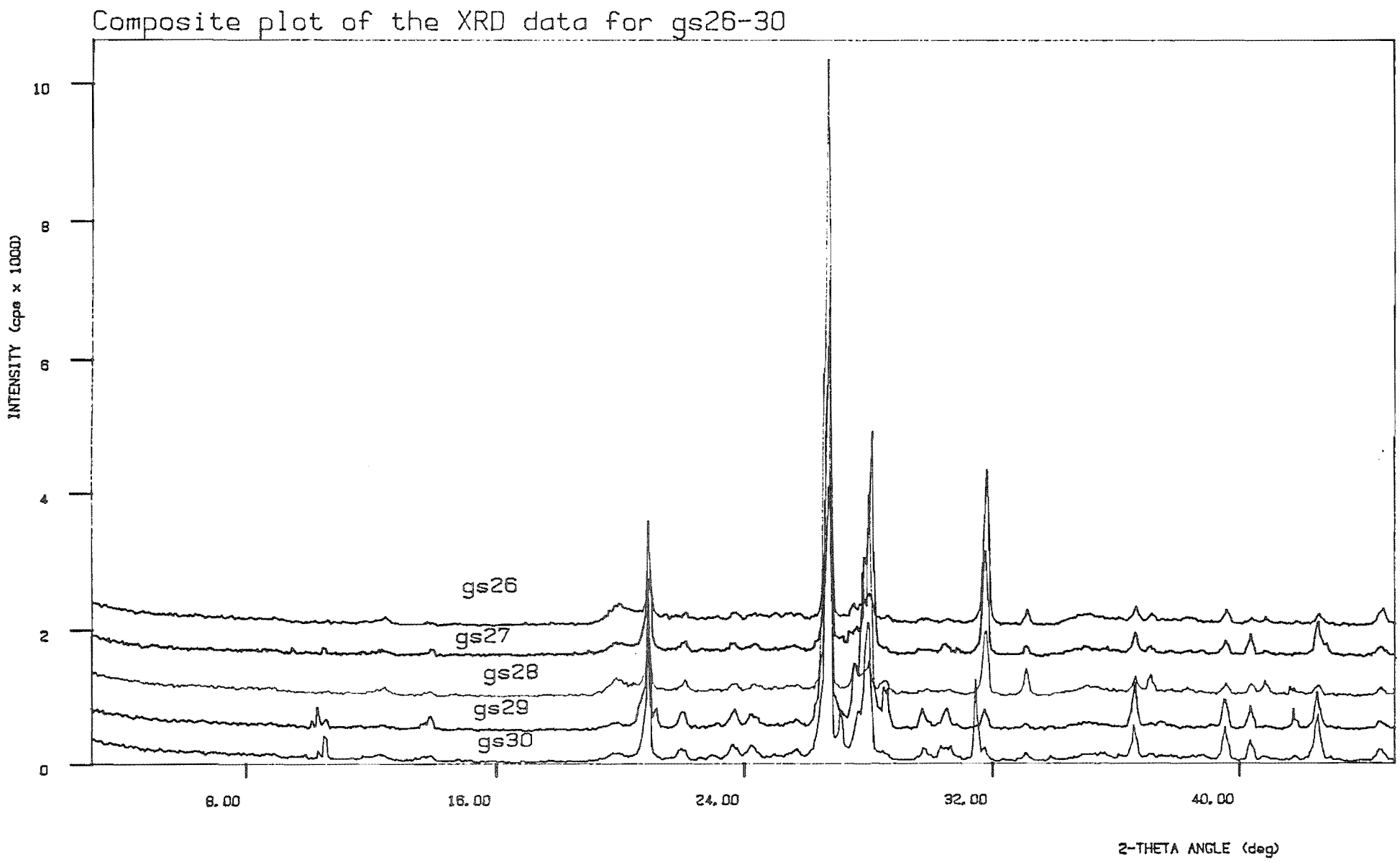

Composite plot of the XRD data for gs06-10
INTENSITY (cps x 1000)
5
4
3
2
1
0
gs06
gs07
gs08
gs09
gs10
8.00
16.00
24.00
32.00
40.00
2-THETA ANGLE (deg)

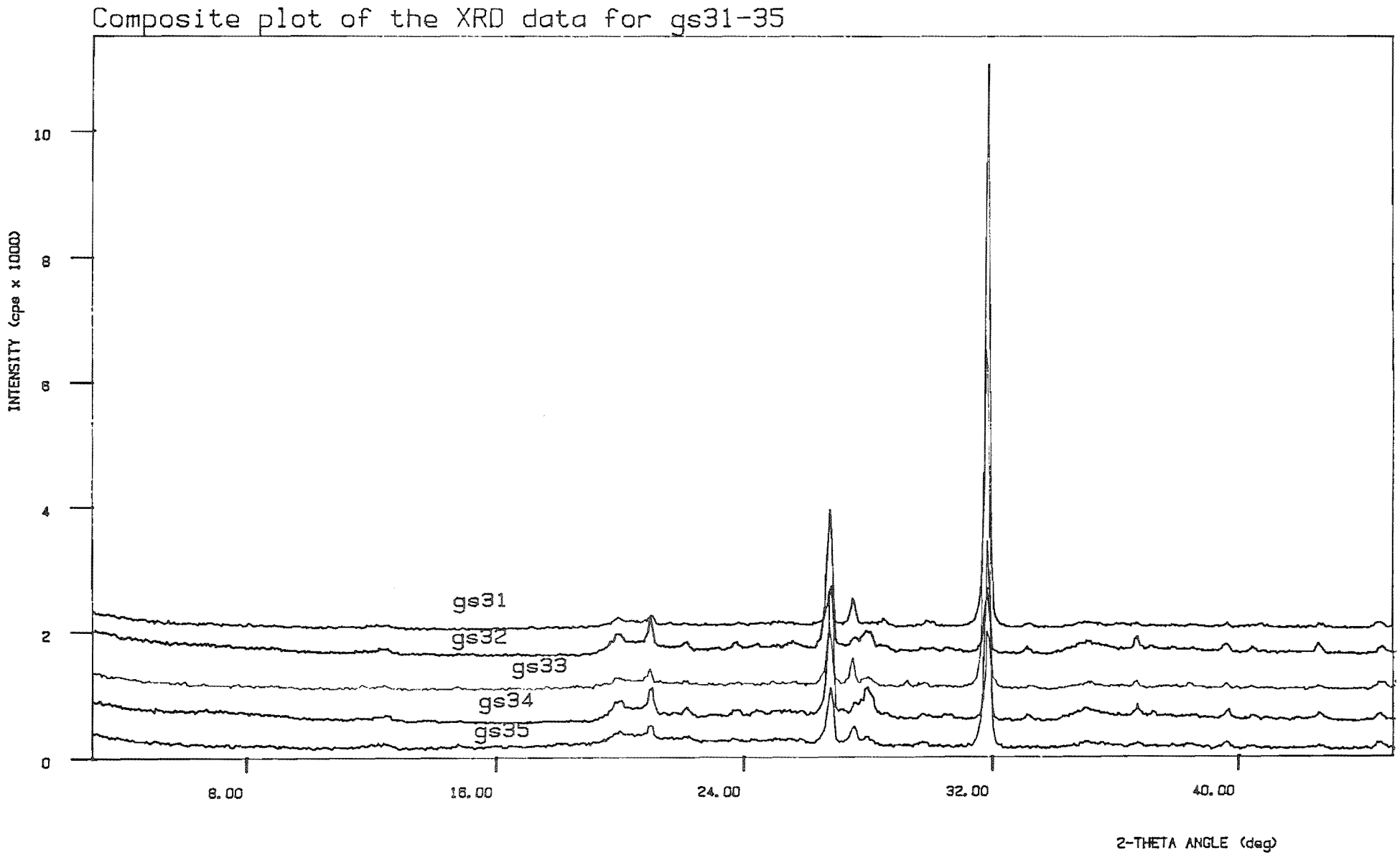

Composite plot of the XRD data for gs11-15
INTENSITY (cps x 1000)
10
8
6
4
2
0
gs11
gs12
gs13
gs14
gs15
8.00
16.00
24.00
32.00
40.00
2-THETA ANGLE (deg)

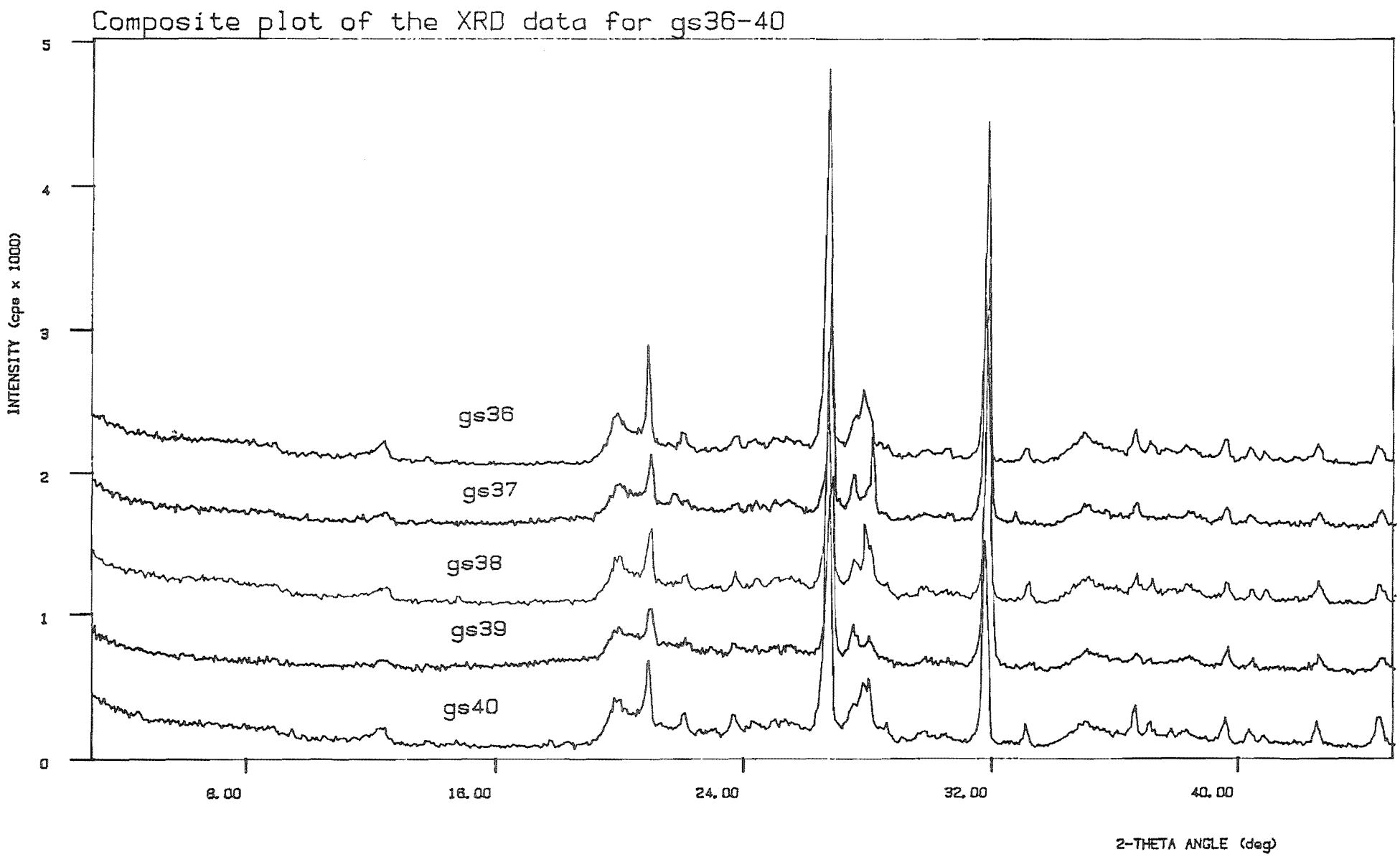

Composite plot of the XRD data for gs16-20
INTENSITY (cps x 1000)
0
1
2
3
4
5
6
7
8
gs16
gs17
gs18
gs19
gs20
8.00
16.00
24.00
32.00
40.00
2-THETA ANGLE (deg)

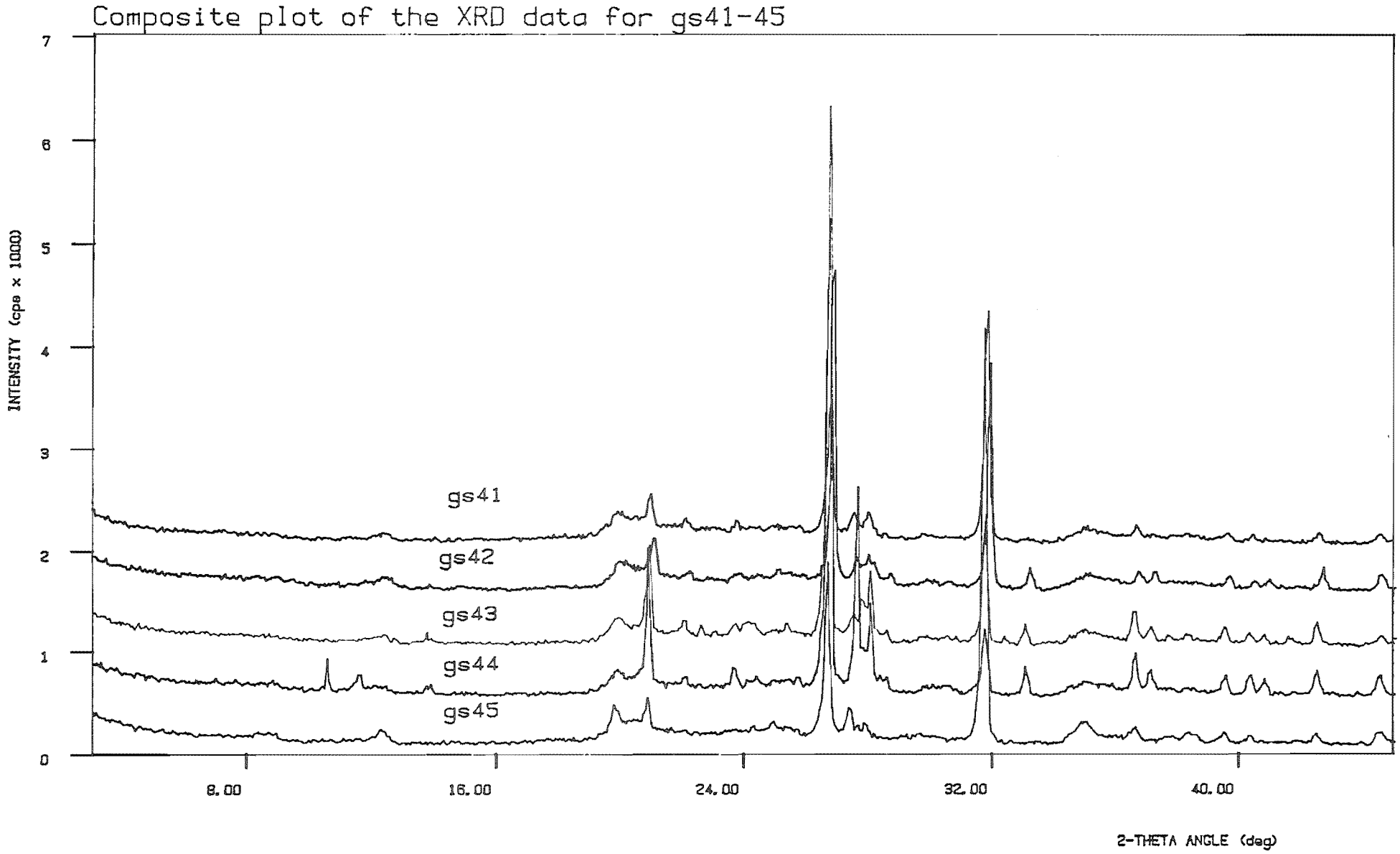

Composite plot of the XRD data for gs21-25
INTENSITY (cps x 1000)
0
1
2
3
4
5
6
gs21
gs22
gs23
gs24
gs25
8.00
16.00
24.00
32.00
40.00
2-THETA ANGLE (deg)

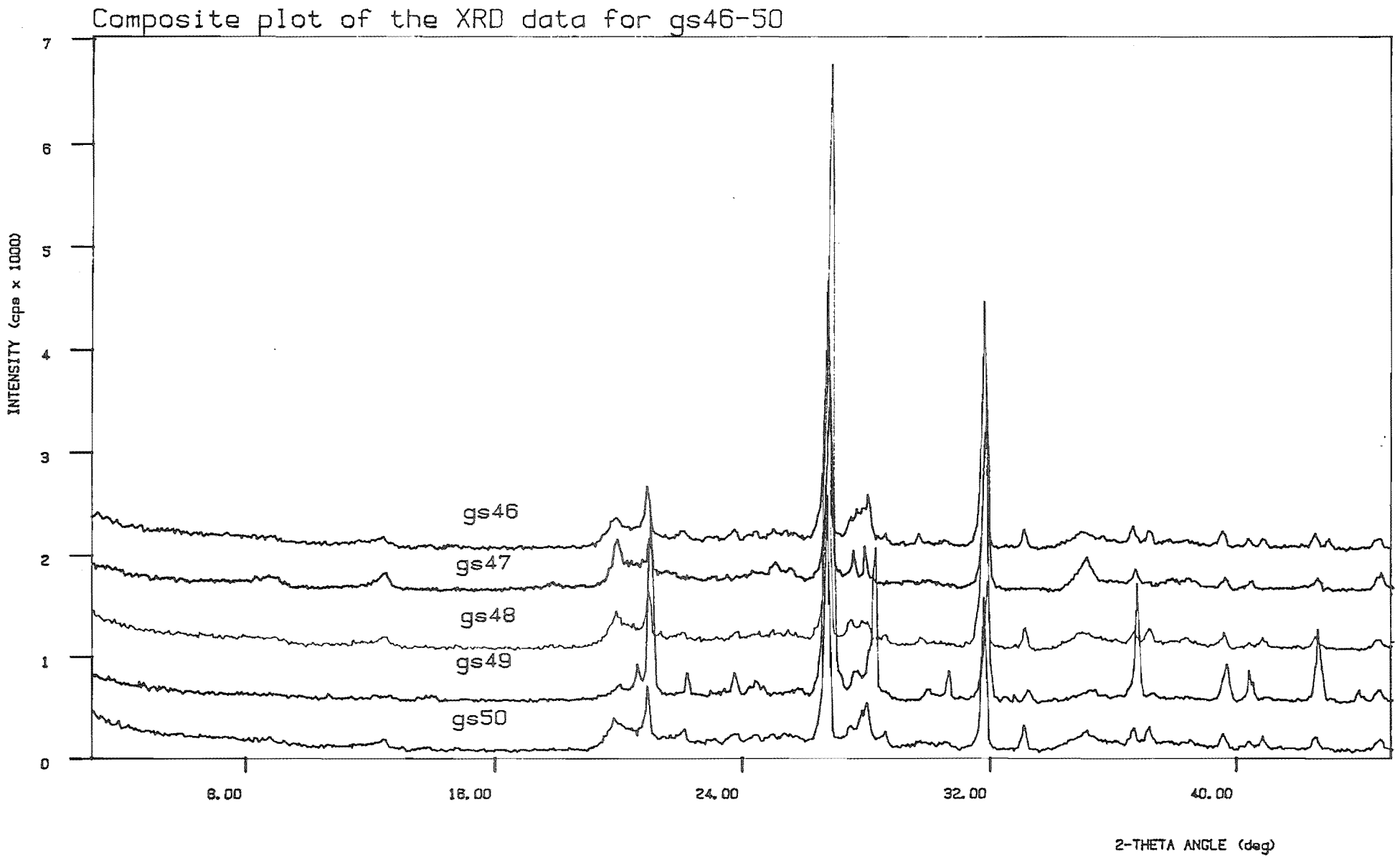
Appendix 1 - 30

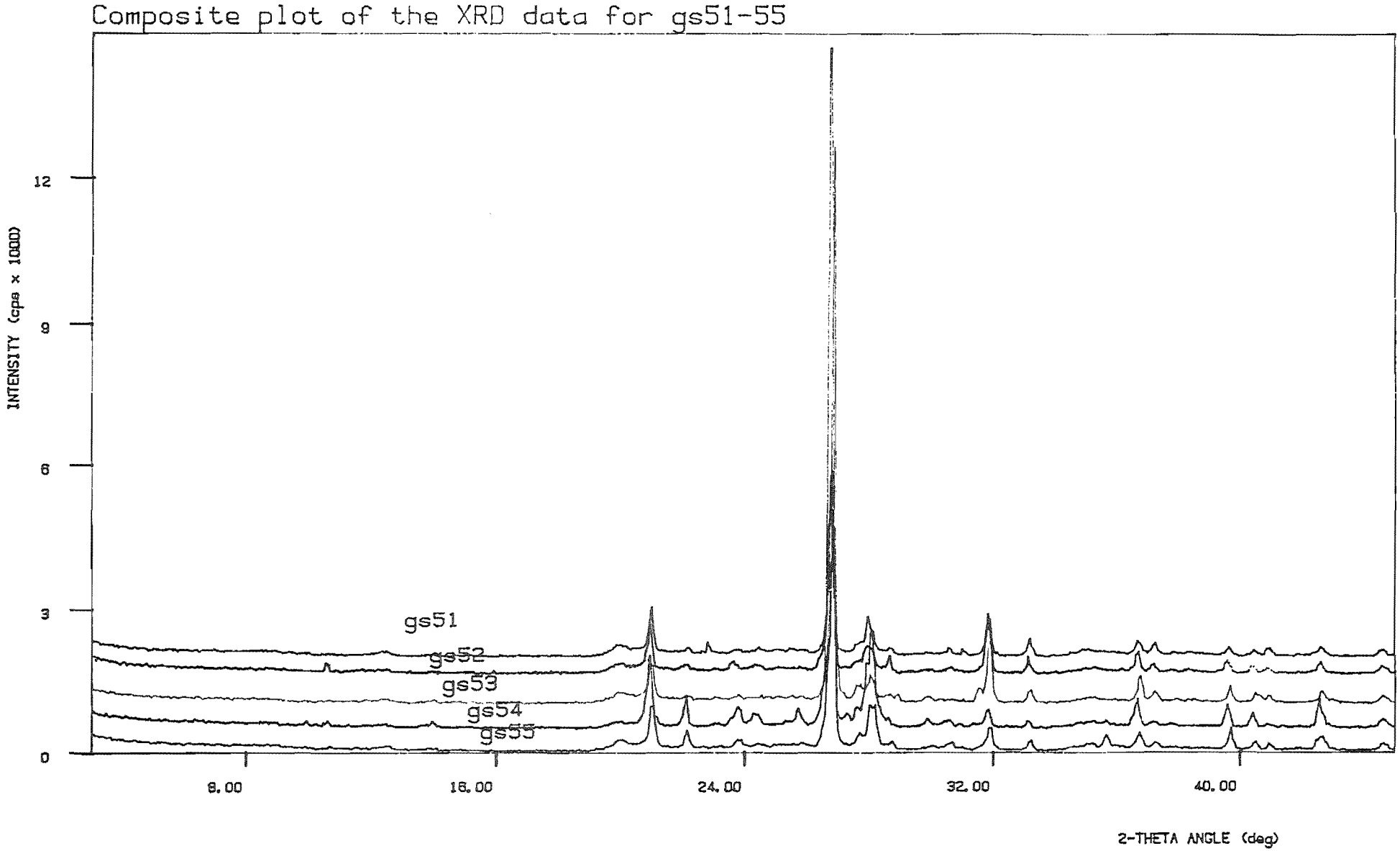


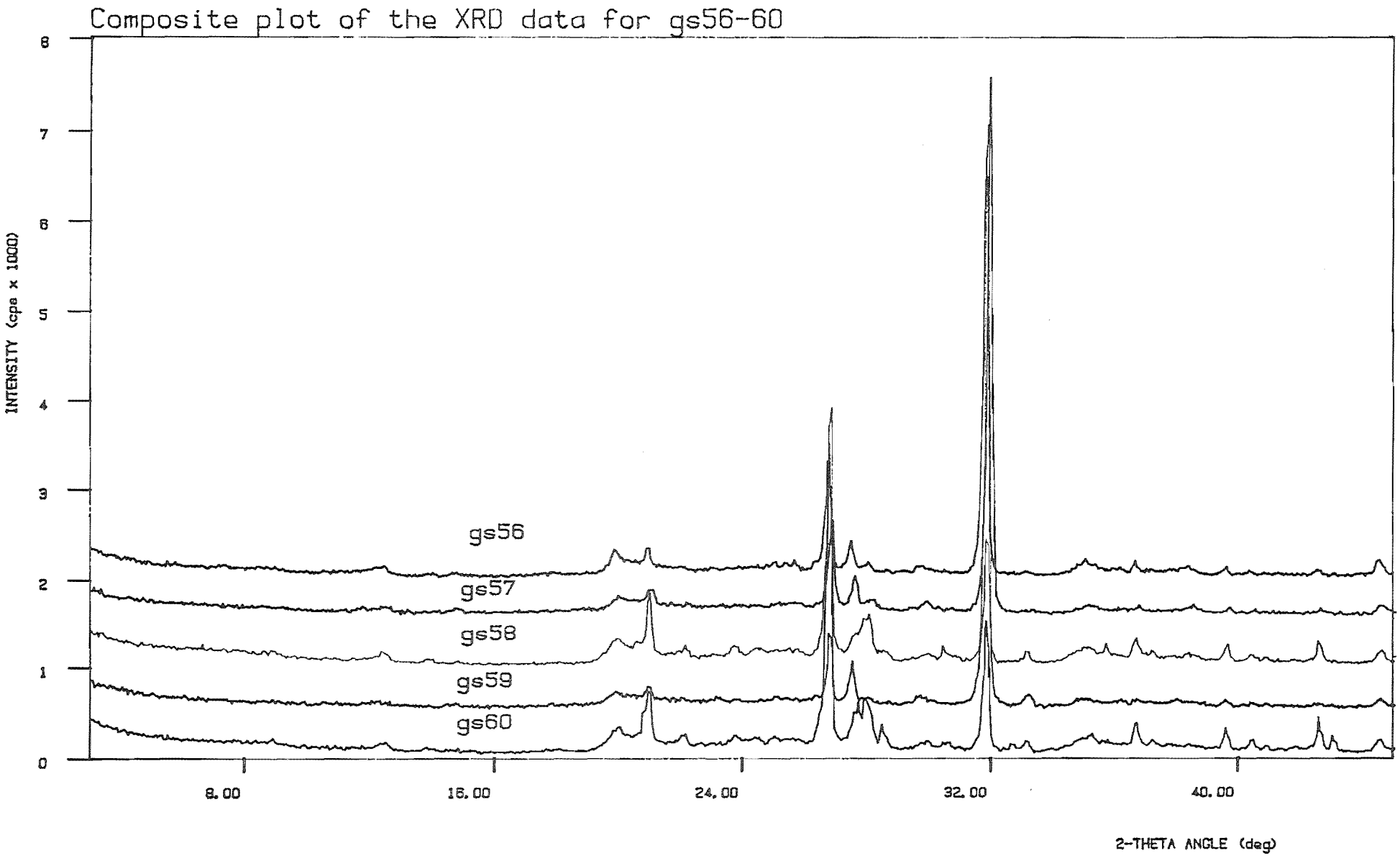

Composite plot of the XRD data for gs31-35
INTENSITY (cps x 1000)
0
2
4
6
8
10
gs31
gs32
gs33
gs34
gs35
8.00
16.00
24.00
32.00
40.00
2-THETA ANGLE (deg)

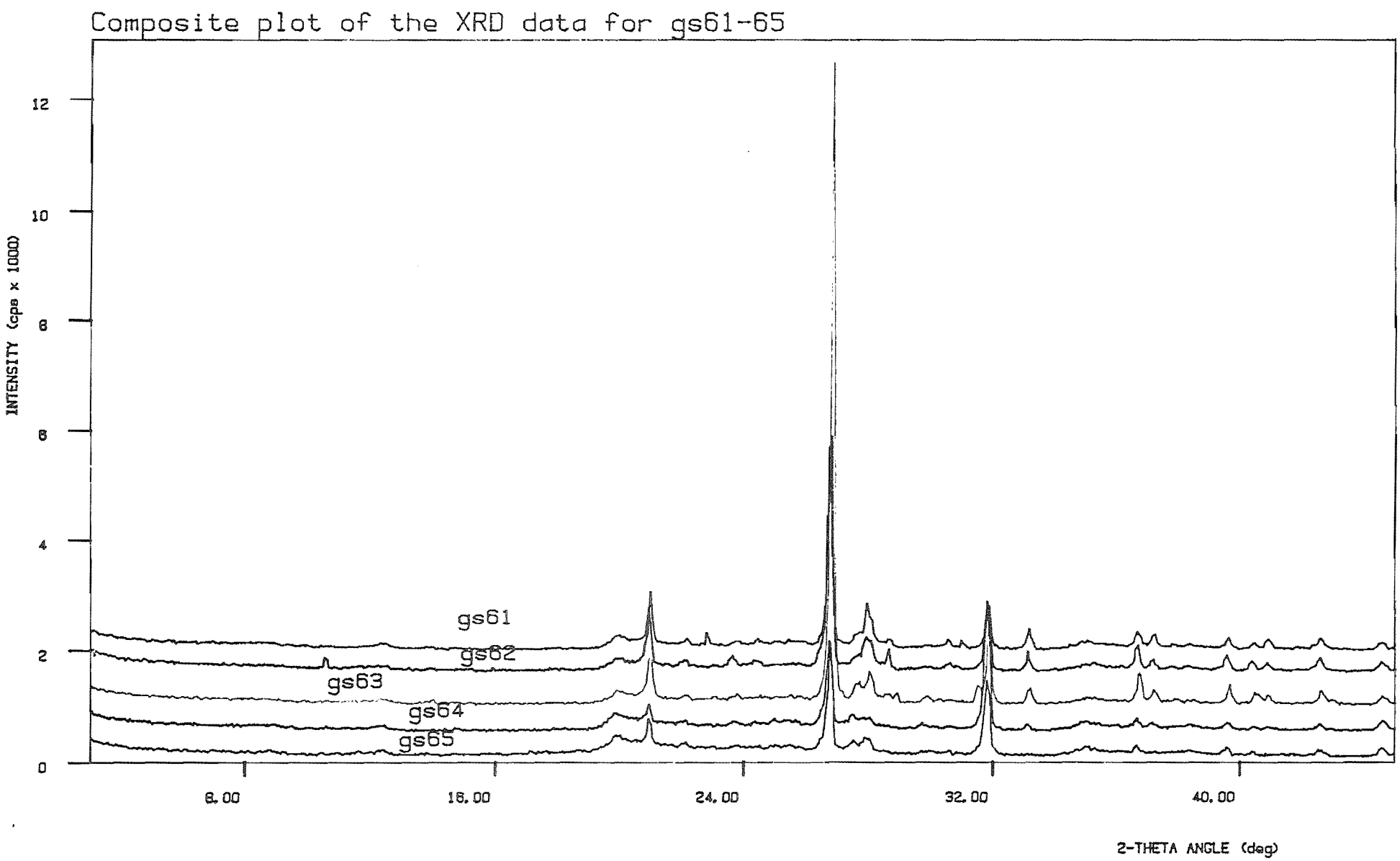

Composite plot of the XRD data for gs36-40
INTENSITY (cps x 1000)
5
4
3
2
1
0
gs36
gs37
gs38
gs39
gs40
8.00
16.00
24.00
32.00
40.00
2-THETA ANGLE (deg)

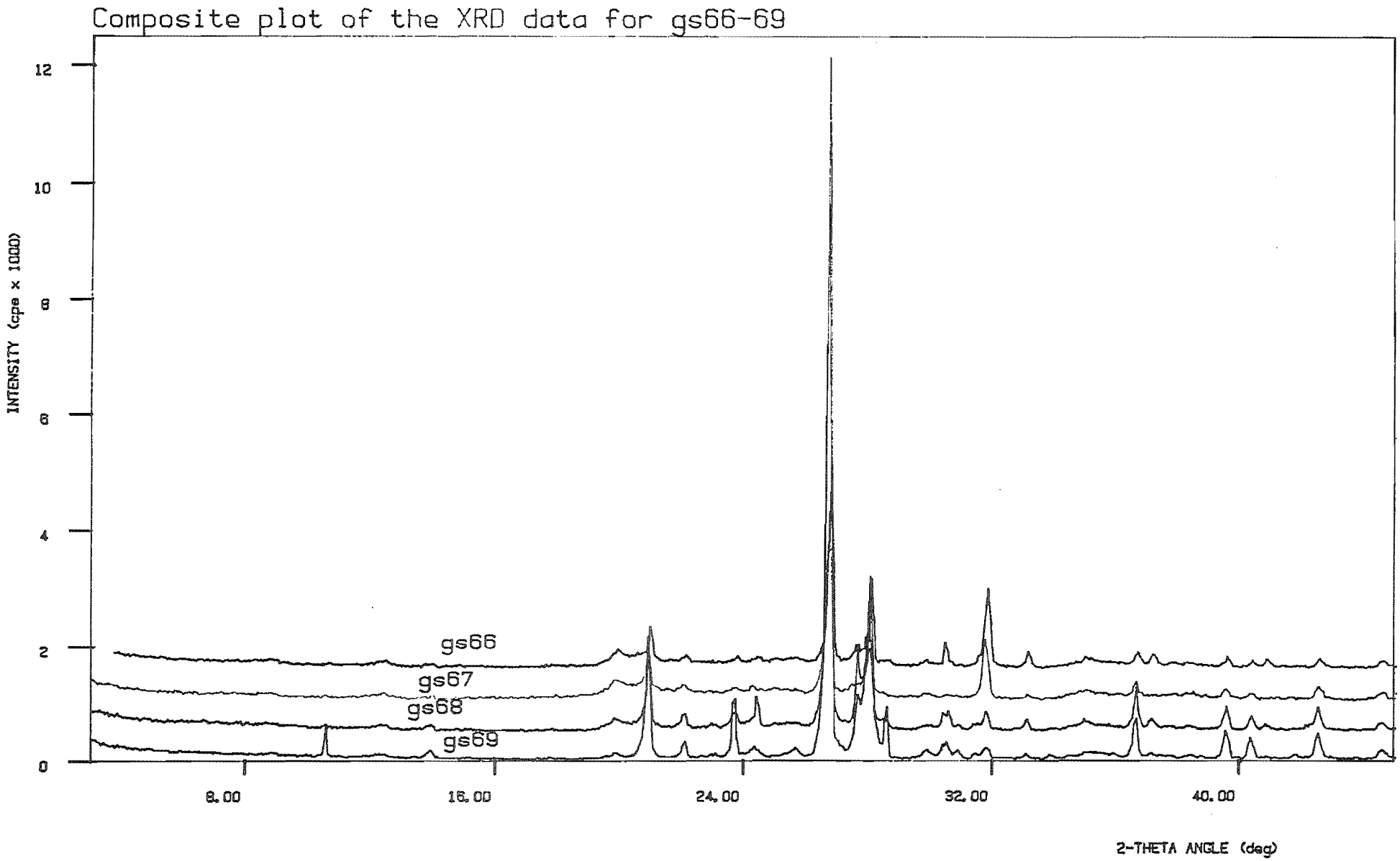

Composite plot of the XRD data for gs41-45
INTENSITY (cps x 1000)
0
1
2
3
4
5
6
7
gs41
gs42
gs43
gs44
gs45
8.00
16.00
24.00
32.00
40.00
2-THETA ANGLE (deg)


Composite plot of the XRD data for gs46-50
INTENSITY (cps x 1000)
0
1
2
3
4
5
6
7
gs46
gs47
gs48
gs49
gs50
8.00
16.00
24.00
32.00
40.00
2-THETA ANGLE (deg)


Composite plot of the XRD data for gs51-55
INTENSITY (cps x 1000)
12
9
6
3
0
gs51
gs52
gs53
gs54
gs55
8.00
16.00
24.00
32.00
40.00
2-THETA ANGLE (deg)


Composite plot of the XRD data for gs56-60
INTENSITY (cps x 1000)
0
1
2
3
4
5
6
7
8
gs56
gs57
gs58
gs59
gs60
8.00
16.00
24.00
32.00
40.00
2-THETA ANGLE (deg)


Composite plot of the XRD data for gs61-65
INTENSITY (cps x 1000)
12
10
8
6
4
2
0
gs61
gs62
gs63
gs64
gs65
8.00
16.00
24.00
32.00
40.00
2-THETA ANGLE (deg)


Composite plot of the XRD data for gs66-69
INTENSITY (cps x 1000)
12
10
8
6
4
2
0
gs66
gs67
gs68
gs69
8.00
16.00
24.00
32.00
40.00
2-THETA ANGLE (deg)

Appendix 2-1

Total Analysis Data

SAMPLE No	DEPTH	WEIGHT	Cu	Zn	Pb	Cd	Hg
MCC 001/01	0-5 CM	1.0720	19.68	44.78	40.49	0.68	0.55
MCC 001/02	10-15 CM	1.0135	44.70	79.75	36.41	0.81	0.80
MCC 001/03	20-25 CM	1.0153	30.14	77.49	31.03	0.56	0.60
MCC 001/04	30-35 CM	1.0042	49.89	78.65	20.31	nd	nd
MCC 001/05	40-45 CM	1.0783	23.74	57.32	9.55	nd	nd
MCC 001/06	50-55 CM	1.0562	23.39	33.26	5.49	nd	1.09
MCC 001/07	75-80 CM	1.2242	12.33	30.20	4.98	nd	0.62
MCC 001/08	100-105 CM	1.2222	13.42	35.26	7.04	0.20	1.75
MCC 001/09	125-130 CM	1.1527	17.09	37.92	6.59	nd	1.66
MCC 002/01	0-5 CM	1.0774	43.07	83.27	48.45	0.87	4.34
MCC 002/02	10-15 CM	1.0231	35.97	73.30	35.38	0.95	6.57
MCC 002/03	20-25 CM	1.0151	21.77	600.50	22.17	1.47	nd
MCC 002/04	30-35 CM	1.0033	23.12	72.92	12.96	nd	nd
MCC 002/05	40-45 CM	1.0342	22.72	75.78	8.61	nd	0.25
MCC 002/06	50-55 CM	1.0830	52.45	79.16	8.49	1.07	nd
MCC 002/07	75-80 CM	1.0487	13.06	34.08	6.39	nd	0.27
MCC 002/08	100-105 CM	1.0642	18.98	42.23	5.96	nd	2.35
MCC 003/01	0-5 CM	1.0101	40.69	63.31	20.10	10.99	3.13
MCC 003/02	15-20 CM	1.0275	29.78	66.42	19.95	0.92	2.00
MCC 003/03	25-30 CM	1.0256	22.04	56.97	9.17	nd	2.25
MCC 003/04	30-35 CM	1.1081	62.32	54.95	4.64	0.48	0.34
MCC 003/05	40-45 CM	1.2939	9.94	50.37	4.49	nd	nd
MCC 003/06	50-55 CM	1.5806	8.14	40.07	3.68	nd	1.86
MCC 003/07	75-80 CM	1.0845	12.46	41.15	3.33	nd	5.38
MCC 003/08	100-105 CM	1.0482	13.00	42.29	5.20	nd	0.27
MCC 004/01	0-5 CM	1.0585	11.07	54.50	26.90	nd	1.72
MCC 004/02	10-15 CM	1.0912	25.03	85.03	28.35	nd	0.88
MCC 004/03	20-25 CM	1.0549	15.61	67.90	9.24	nd	nd
MCC 004/04	30-35 CM	1.0674	16.45	30.61	4.82	nd	nd
MCC 004/05	40-45 CM	1.0053	16.41	38.30	3.84	nd	0.94
MCC 004/06	50-55 CM	1.1048	20.13	49.28	4.61	nd	nd
MCC 004/07	75-80 CM	1.0652	13.27	35.57	4.61	nd	nd
MCC 005/01	0-5 CM	1.0036	38.25	100.09	35.56	0.46	nd
MCC 005/02	10-15 CM	1.0081	18.06	64.66	39.84	nd	0.32
MCC 005/03	20-25 CM	1.1035	19.22	68.24	19.16	nd	1.77
MCC 005/04	30-35 CM	1.0183	23.90	62.81	9.71	nd	nd
MCC 005/05	40-45 CM	1.0097	15.78	55.44	4.96	nd	nd
MCC 005/06	50-55 CM	1.1065	9.73	34.79	4.74	nd	nd
MCC 005/07	75-80 CM	1.0688	10.12	34.30	4.79	nd	nd
MCC 005/08	100-105 CM	1.0223	11.88	40.66	5.23	nd	nd
MCC 006/01	0-5 CM	1.0333	24.13	70.50	32.12	nd	1.94
MCC 006/02	10-15 CM	1.0456	20.75	74.07	23.55	nd	1.32
MCC 006/03	20-25 CM	1.0224	18.20	69.75	19.49	nd	0.20
MCC 006/04	30-35 CM	1.0781	34.89	63.31	15.55	nd	2.12
MCC 006/05	40-45 CM	1.0115	18.87	49.28	8.96	nd	nd
MCC 006/06	50-55 CM	1.0420	18.20	61.08	8.63	nd	1.07
MCC 006/07	75-80 CM	1.0198	11.45	31.74	5.31	nd	0.20
MCC 006/08	100-105 CM	1.0407	7.85	42.95	3.63	nd	0.72
MCC 007/01	0-5 CM	1.2372	21.31	30.62	20.36	nd	2.82
MCC 007/02	10-15 CM	1.0396	17.78	79.50	20.12	nd	0.63
MCC 007/03	20-25 CM	1.0124	32.99	73.47	10.07	nd	0.48
MCC 007/04	30-35 CM	1.0338	29.21	41.69	4.76	nd	0.66
MCC 007/05	40-45 CM	1.0508	16.48	41.60	4.66	nd	0.13
MCC 007/06	50-55 CM	1.0803	12.10	40.75	4.08	nd	6.50
MCC 007/07	75-80 CM	1.1284	13.85	36.84	4.06	nd	0.57
MCC 008/01	0-5 CM	1.0252	60.55	77.94	34.84	0.51	15.38
MCC 008/02	10-15 CM	1.0118	47.43	190.26	45.41	1.34	7.72
MCC 008/03	20-25 CM	1.0194	35.52	77.18	20.52	0.61	nd
MCC 008/04	30-35 CM	1.0076	27.73	61.65	8.86	0.48	0.37
MCC 008/05	40-45 CM	1.0228	24.11	47.24	6.89	nd	0.29
MCC 008/06	50-55 CM	1.0418	24.50	51.09	7.48	0.40	0.85
MCC 008/07	75-80 CM	1.0348	12.80	83.74	4.71	0.60	0.91
MCC 008/08	100-105 CM	1.1281	11.05	36.58	4.67	nd	0.88
MCC 009/01	0-5 CM	1.0231	19.93	58.91	17.24	0.85	1.29

(N/A) Not analysed.

(nd) Not detected

Samples that were lost during analysis are in shaded boxes

Appendix 2-2

Total Analysis Data

SAMPLE No	DEPTH	WEIGHT	Cu	Zn	Pb	Cd	Hg
MCC 009/02	10-15 CM	1.0032	25.49	68.03	19.96	nd	1.24
MCC 009/03	20-25 CM	1.2534	17.71	88.95	6.63	0.67	0.90
MCC 009/04	30-35 CM	1.0591	28.10	56.62	11.14	nd	0.61
MCC 009/05	40-45 CM	1.0131	12.16	60.47	5.66	nd	nd
MCC 009/06	50-55 CM	1.0356	12.73	36.88	5.31	nd	0.20
MCC 009/07	75-80 CM	1.0797	14.17	39.92	4.12	nd	1.32
MCC 009/08	100-105 CM	1.0414	27.95	59.06	9.76	nd	2.15
MCC 010/01	0-5 CM	1.0222	28.97	93.24	28.22	0.87	0.76
MCC 010/02	10-15 CM	1.0426	27.16	76.35	20.19	nd	2.69
MCC 010/03	20-25 CM	1.0176	35.98	62.85	12.25	nd	0.22
MCC 010/04	30-35 CM	1.0552	25.96	85.90	10.46	nd	0.22
MCC 010/05	40-45 CM	1.2130	30.09	81.30	9.53	0.35	1.52
MCC 010/06	50-55 CM	1.0298	16.94	49.89	4.95	nd	nd
MCC 010/07	75-80 CM	1.0287	57.80	51.44	3.17	nd	17.45
MCC 011/01	0-5 CM	1.0809	32.47	71.09	41.81	1.09	1.50
MCC 011/02	10-15 CM	1.0289	29.79	53.81	25.82	1.66	0.74
MCC 011/03	20-25 CM	1.0831	25.84	63.30	11.80	nd	0.83
MCC 011/04	30-35 CM	1.1026	15.60	47.43	5.86	nd	0.07
MCC 011/05	40-45 CM	1.0383	12.84	41.81	5.99	nd	0.19
MCC 011/06	50-55 CM	1.0573	15.27	45.41	5.65	nd	0.18
MCC 011/07	75-80 CM	1.0081	24.42	160.26	3.22	nd	2.40
MCC 012/01	0-5 CM	1.0245	43.25	94.46	55.69	1.53	0.17
MCC 012/02	10-15 CM	1.0305	39.36	57.60	30.26	0.64	5.59
MCC 012/03	20-25 CM	1.0143	61.54	81.45	29.30	0.28	1.22
MCC 012/04	30-35 CM	1.0390	28.86	104.06	24.90	nd	nd
MCC 012/05	40-45 CM	1.0380	40.85	86.43	12.47	nd	2.82
MCC 012/06	50-55 CM	1.0106	27.76	46.90	9.63	nd	nd
MCC 012/07	75-80 CM	1.0381	113.27	155.89	12.73	0.27	68.47

(N/A) Not analysed.

(nd) Not detected

Samples that were lost during analysis are in shaded boxes.

Appendix 2-3

Total AnalysisData

SAMPLE No	DEPTH	Cr	Ni	Sn	Fe %
MCC 001/01	0-5 CM	2.62	11.79	119.06	2.10
MCC 001/02	10-15 CM	6.34	21.70	190.76	1.93
MCC 001/03	20-25 CM	7.68	25.75	190.42	2.88
MCC 001/04	30-35 CM	5.42	30.27	174.57	3.94
MCC 001/05	40-45 CM	5.60	24.25	157.01	3.78
MCC 001/06	50-55 CM	3.65	11.35	132.07	3.18
MCC 001/07	75-80 CM	2.71	10.86	89.78	4.05
MCC 001/08	100-105 CM	2.95	15.76	128.74	2.62
MCC 001/09	125-130 CM	5.69	13.24	100.47	1.44
MCC 002/01	0-5 CM	4.41	19.14	168.28	2.04
MCC 002/02	10-15 CM	5.22	20.82	183.08	4.43
MCC 002/03	20-25 CM	9.38	50.68	202.35	5.99
MCC 002/04	30-35 CM	7.17	33.17	192.70	4.48
MCC 002/05	40-45 CM	5.43	22.59	140.62	2.40
MCC 002/06	50-55 CM	3.17	15.32	117.85	2.97
MCC 002/07	75-80 CM	2.42	15.18	87.99	2.75
MCC 002/08	100-105 CM	3.28	13.10	92.23	2.38
MCC 003/01	0-5 CM	1.96	20.42	102.98	2.24
MCC 003/02	15-20 CM	6.17	26.82	164.77	4.47
MCC 003/03	25-30 CM	5.20	23.46	130.22	4.03
MCC 003/04	30-35 CM	2.73	20.46	104.51	2.55
MCC 003/05	40-45 CM	2.64	17.53	89.50	2.36
MCC 003/06	50-55 CM	2.05	15.22	84.50	1.72
MCC 003/07	75-80 CM	1.67	17.77	145.09	1.48
MCC 003/08	100-105 CM	3.70	24.95	127.41	2.89
MCC 004/01	0-5 CM	1.75	5.33	114.99	0.93
MCC 004/02	10-15 CM	5.47	19.52	188.24	1.62
MCC 004/03	20-25 CM	5.86	28.14	166.18	4.28
MCC 004/04	30-35 CM	4.80	18.05	147.41	2.49
MCC 004/05	40-45 CM	5.40	23.24	138.75	1.94
MCC 004/06	50-55 CM	4.19	13.22	78.22	2.18
MCC 004/07	75-80 CM	4.51	16.20	75.64	1.67
MCC 005/01	0-5 CM	3.69	17.86	168.70	0.69
MCC 005/02	10-15 CM	4.34	22.49	162.01	1.83
MCC 005/03	20-25 CM	5.35	29.50	137.19	2.80
MCC 005/04	30-35 CM	6.96	39.20	172.15	3.92
MCC 005/05	40-45 CM	3.98	25.20	144.03	3.03
MCC 005/06	50-55 CM	3.32	19.25	88.70	2.19
MCC 005/07	75-80 CM	2.64	18.03	75.39	1.49
MCC 005/08	100-105 CM	2.54	85.72	90.27	1.45
MCC 006/01	0-5 CM	4.46	16.70	5.25	1.35
MCC 006/02	10-15 CM	6.28	19.72	5.19	2.27
MCC 006/03	20-25 CM	5.90	20.17	5.30	3.26
MCC 006/04	30-35 CM	7.11	27.53	58.52	4.12
MCC 006/05	40-45 CM	6.71	22.42	39.45	3.67
MCC 006/06	50-55 CM	5.03	18.49	43.84	3.29
MCC 006/07	75-80 CM	3.24	13.68	16.55	1.91
MCC 006/08	100-105 CM	3.75	12.77	38.34	1.66
MCC 007/01	0-5 CM	2.42	3.06	4.38	1.53
MCC 007/02	10-15 CM	6.03	29.93	71.89	4.01
MCC 007/03	20-25 CM	6.02	31.44	62.31	4.19
MCC 007/04	30-35 CM	4.79	19.29	16.33	3.52
MCC 007/05	40-45 CM	4.63	14.52	27.00	2.19
MCC 007/06	50-55 CM	3.78	12.91	31.60	1.82
MCC 007/07	75-80 CM	3.74	15.88	20.05	1.61
MCC 008/01	0-5 CM	4.19	9.81	5.29	0.94
MCC 008/02	10-15 CM	5.34	21.73	5.36	2.41
MCC 008/03	20-25 CM	5.93	29.82	22.19	3.66
MCC 008/04	30-35 CM	6.42	30.88	56.84	4.64
MCC 008/05	40-45 CM	4.56	22.17	44.67	2.47
MCC 008/06	50-55 CM	4.39	20.45	21.71	3.21
MCC 008/07	75-80 CM	3.14	16.03	16.31	1.94
MCC 008/08	100-105 CM	3.19	17.08	20.05	1.69
MCC 009/01	0-5 CM	4.21	9.83	5.30	1.94

Appendix 2-4

Total Analysis Data

SAMPLE No	DEPTH	Cr	Ni	Sn	Fe %
MCC 009/02	10-15 CM	5.43	21.92	5.41	3.00
MCC 009/03	20-25 CM	2.58	13.76	4.33	2.42
MCC 009/04	30-35 CM	4.87	22.71	37.68	3.43
MCC 009/05	40-45 CM	2.93	15.72	16.66	2.18
MCC 009/06	50-55 CM	2.48	15.38	5.24	1.80
MCC 009/07	75-80 CM	1.98	18.47	123.69	1.56
MCC 009/08	100-105 CM	3.42	31.96	38.32	3.09
MCC 010/01	0-5 CM	4.56	21.51	5.31	3.19
MCC 010/02	10-15 CM	4.38	25.08	5.20	3.49
MCC 010/03	20-25 CM	4.93	29.87	73.44	4.43
MCC 010/04	30-35 CM	3.34	24.78	43.30	3.02
MCC 010/05	40-45 CM	2.52	25.65	32.90	2.83
MCC 010/06	50-55 CM	3.17	18.71	33.15	2.00
MCC 010/07	75-80 CM	3.84	57.78	84.01	3.99
MCC 011/01	0-5 CM	4.08	19.08	10.31	1.90
MCC 011/02	10-15 CM	4.17	18.73	21.99	1.99
MCC 011/03	20-25 CM	6.75	23.50	69.00	3.13
MCC 011/04	30-35 CM	3.92	16.25	15.31	2.43
MCC 011/05	40-45 CM	4.09	15.34	16.26	2.23
MCC 011/06	50-55 CM	3.63	15.06	21.39	2.08
MCC 011/07	75-80 CM	3.31	4.37	33.86	0.25
MCC 012/01	0-5 CM	3.88	19.47	10.88	1.08
MCC 012/02	10-15 CM	6.46	22.67	49.95	1.25
MCC 012/03	20-25 CM	7.35	29.26	114.17	2.68
MCC 012/04	30-35 CM	7.66	30.64	88.82	3.32
MCC 012/05	40-45 CM	5.72	29.28	88.90	2.54
MCC 012/06	50-55 CM	5.35	18.40	39.49	3.40
MCC 012/07	75-80 CM	14.83	135.61	66.38	6.03

Appendix 2-5

BaCl/ NH4ClExtractable

SAMPLE No	DEPTH	WEIGHT	Cd	Pb	Cu	Zn	Hg
MCC 001/01	0-5 CM	2.09	nd	2.01	0.71	1.10	0.13
MCC 001/02	10-15 CM	2.02	nd	3.13	1.58	2.14	nd
MCC 001/03	20-25 CM	2.01	nd	3.02	0.58	1.45	nd
MCC 001/04	30-35 CM	2.03	nd	1.95	0.35	1.37	nd
MCC 001/05	40-45 CM	2.13	nd	1.73	0.40	1.01	nd
MCC 001/06	50-55 CM	2.02	nd	2.09	0.12	11.02	nd
MCC 001/07	75-80 CM	2.10	nd	1.88	0.18	7.38	nd
MCC 001/08	100-105 CM	2.08	nd	1.77	0.19	6.06	nd
MCC 001/09	125-130 CM	2.03	nd	1.56	0.02	0.59	nd
MCC 002/01	0-5 CM	2.02	nd	2.61	0.73	1.21	nd
MCC 002/02	10-15 CM	2.04	nd	2.71	0.42	1.23	nd
MCC 002/03	20-25 CM	2.15	nd	3.44	0.98	379.20	nd
MCC 002/04	30-35 CM	2.07	nd	2.42	0.34	0.82	nd
MCC 002/05	40-45 CM	2.03	nd	2.72	0.34	15.13	nd
MCC 002/06	50-55 CM	2.04	nd	1.94	0.04	4.06	nd
MCC 002/07	75-80 CM	2.11	nd	1.62	0.04	0.62	nd
MCC 002/08	100-105 CM	2.07	nd	1.66	0.02	0.57	nd
MCC 003/01	0-5 CM	2.08	nd	1.90	0.26	1.07	nd
MCC 003/02	15-20 CM	2.02	nd	9.42	6.32	24.78	nd
MCC 003/03	25-30 CM	2.06	nd	2.94	1.48	18.18	nd
MCC 003/04	30-35 CM	2.08	nd	2.15	0.49	1.19	0.01
MCC 003/05	40-45 CM	2.06	nd	1.92	0.42	1.14	nd
MCC 003/06	50-55 CM	2.13	nd	1.61	0.11	0.51	nd
MCC 003/07	75-80 CM	2.02	nd	1.83	0.04	0.57	nd
MCC 003/08	100-105 CM	2.03	nd	1.81	0.34	1.13	nd
MCC 004/01	0-5 CM	2.16	nd	2.32	0.76	1.41	nd
MCC 004/02	10-15 CM	2.00	nd	7.70	9.18	63.08	nd
MCC 004/03	20-25 CM	2.02	nd	2.35	0.58	1.27	0.01
MCC 004/04	30-35 CM	2.08	nd	2.53	0.56	13.45	nd
MCC 004/05	40-45 CM	2.01	nd	3.80	0.81	13.58	nd
MCC 004/06	50-55 CM	2.02	nd	2.22	0.27	12.93	nd
MCC 004/07	75-80 CM	2.09	nd	2.02	0.19	5.04	nd
MCC 005/01	0-5 CM	2.00	nd	3.68	1.44	3.70	nd
MCC 005/02	10-15 CM	2.01	nd	2.88	0.74	1.35	nd
MCC 005/03	20-25 CM	2.08	nd	2.53	0.41	1.43	nd
MCC 005/04	30-35 CM	2.04	nd	2.84	0.88	2.95	0.01
MCC 005/05	40-45 CM	2.08	nd	3.54	0.86	17.66	nd
MCC 005/06	50-55 CM	2.07	nd	3.57	1.25	12.92	nd
MCC 005/07	75-80 CM	2.04	nd	2.07	0.34	0.91	nd
MCC 005/08	100-105 CM	2.02	nd	2.09	0.27	0.88	nd
MCC 006/01	0-5 CM	2.10	nd	4.40	2.12	10.90	nd
MCC 006/02	10-15 CM	2.14	nd	2.83	0.55	3.56	nd
MCC 006/03	20-25 CM	2.03	nd	3.12	0.65	21.05	nd
MCC 006/04	30-35 CM	2.11	nd	2.87	0.63	10.54	nd
MCC 006/05	40-45 CM	2.04	nd	4.28	0.65	14.80	0.02
MCC 006/06	50-55 CM	2.03	nd	2.85	0.58	30.02	nd
MCC 006/07	75-80 CM	2.05	nd	2.05	0.11	5.51	nd
MCC 006/08	100-105 CM	2.14	nd	1.97	0.11	0.52	nd
MCC 007/01	0-5 CM	2.00	nd	2.37	0.35	0.63	nd
MCC 007/02	10-15 CM	2.02	nd	2.35	0.58	0.82	0.02
MCC 007/03	20-25 CM	2.01	nd	1.97	0.43	1.68	nd
MCC 007/04	30-35 CM	2.06	nd	2.43	0.64	6.52	nd
MCC 007/05	40-45 CM	2.03	nd	2.34	0.50	10.65	nd
MCC 007/06	50-55 CM	2.03	nd	1.82	0.42	3.02	nd
MCC 007/07	75-80 CM	2.17	nd	1.70	0.25	0.64	nd
MCC 008/01	0-5 CM	2.08	nd	3.17	0.49	1.54	nd
MCC 008/02	10-15 CM	2.01	nd	3.28	0.58	17.14	nd
MCC 008/03	20-25 CM	2.10	nd	2.13	1.00	2.33	nd
MCC 008/04	30-35 CM	2.10	nd	2.26	0.41	1.42	nd
MCC 008/05	40-45 CM	2.04	nd	2.32	0.34	0.85	nd
MCC 008/06	50-55 CM	2.04	nd	2.32	0.34	2.46	nd
MCC 008/07	75-80 CM	2.02	nd	2.09	0.12	1.49	nd
MCC 008/08	100-105 CM	2.01	nd	1.96	0.04	0.49	nd
MCC 009/01	0-5 CM	2.01	nd	2.36	0.35	19.18	nd

Appendix 2-6

BaCl/ NH4ClExtractable

SAMPLE No	DEPTH		WEIGHT	Cd	Pb	Cu	Zn	Hg
MCC 009/02	10-15 CM		2.04	nd	2.07	0.42	1.18	nd
MCC 009/03	20-25 CM		2.02	nd	2.09	0.42	6.98	nd
MCC 009/04	30-35 CM		2.09	nd	2.39	0.48	11.33	nd
MCC 009/05	40-45 CM		2.00	nd	1.98	0.51	1.12	nd
MCC 009/06	50-55 CM		2.04	nd	1.81	0.34	1.19	nd
MCC 009/07	75-80 CM		2.03	nd	1.95	0.35	1.02	nd
MCC 009/08	100-105 CM		2.01	nd	1.97	0.12	0.55	nd
MCC 010/01	0-5 CM		2.03	nd	2.98	0.88	43.80	nd
MCC 010/02	10-15 CM		2.01	nd	2.88	0.35	27.50	0.01
MCC 010/03	20-25 CM		2.03	nd	2.47	0.58	11.79	nd
MCC 010/04	30-35 CM		2.07	nd	2.54	0.49	15.17	nd
MCC 010/05	40-45 CM		2.04	nd	2.20	0.34	1.36	nd
MCC 010/06	50-55 CM		2.10	nd	2.26	1.15	1.29	nd
MCC 010/07	75-80 CM		2.03	nd	2.20	0.50	1.39	0.01
MCC 011/01	0-5 CM		2.05	nd	2.82	0.34	4.20	nd
MCC 011/02	10-15 CM		2.04	nd	2.84	0.34	1.15	0.01
MCC 011/03	20-25 CM		2.06	nd	2.56	0.49	8.77	nd
MCC 011/04	30-35 CM		2.01	nd	2.36	0.58	12.42	nd
MCC 011/05	40-45 CM		2.06	nd	2.04	0.49	20.49	nd
MCC 011/06	50-55 CM		2.07	nd	2.29	0.41	0.95	nd
MCC 011/07	75-80 CM		2.04	nd	2.19	0.19	1.00	nd
MCC 012/01	0-5 CM		2.00	nd	3.42	1.13	13.55	0.01
MCC 012/02	10-15 CM		2.05	nd	3.60	0.49	2.93	nd
MCC 012/03	20-25 CM		2.02	nd	3.39	0.58	3.00	nd
MCC 012/04	30-35 CM		2.04	nd	2.98	0.65	1.57	nd
MCC 012/05	40-45 CM		2.06	nd	2.69	0.34	0.93	nd
MCC 012/06	50-55 CM		2.06	nd	2.82	0.26	2.14	nd
MCC 012/07	75-80 CM		2.06	nd	2.42	0.49	2.63	nd

Appendix 2-7

BaCl/ NH4Cl Extractable

SAMPLE No	DEPTH	Cr	Ni	Fe %
MCC 001/01	0-5 CM	0.21	0.26	0.0001
MCC 001/02	10-15 CM	0.18	1.14	0.0003
MCC 001/03	20-25 CM	0.22	1.42	0.0003
MCC 001/04	30-35 CM	0.15	0.96	0.0013
MCC 001/05	40-45 CM	0.18	1.00	0.0002
MCC 001/06	50-55 CM	0.19	2.80	0.0128
MCC 001/07	75-80 CM	0.18	1.27	0.0063
MCC 001/08	100-105 CM	0.18	1.20	0.0093
MCC 001/09	125-130 CM	0.22	0.44	0.0004
MCC 002/01	0-5 CM	0.15	1.15	0.0004
MCC 002/02	10-15 CM	0.22	0.87	0.0011
MCC 002/03	20-25 CM	0.21	4.46	0.0022
MCC 002/04	30-35 CM	0.21	0.86	0.0010
MCC 002/05	40-45 CM	0.25	3.53	0.0146
MCC 002/06	50-55 CM	0.25	1.22	0.0054
MCC 002/07	75-80 CM	0.18	0.42	0.0003
MCC 002/08	100-105 CM	0.18	0.60	0.0003
MCC 003/01	0-5 CM	0.21	0.85	0.0005
MCC 003/02	15-20 CM	0.19	4.34	0.0144
MCC 003/03	25-30 CM	0.18	3.39	0.0121
MCC 003/04	30-35 CM	0.18	3.36	0.0126
MCC 003/05	40-45 CM	0.18	1.03	0.0003
MCC 003/06	50-55 CM	0.18	0.75	0.0001
MCC 003/07	75-80 CM	0.19	0.79	0.0002
MCC 003/08	100-105 CM	0.18	0.96	0.0003
MCC 004/01	0-5 CM	0.17	1.07	0.0003
MCC 004/02	10-15 CM	0.26	2.34	0.0011
MCC 004/03	20-25 CM	0.19	1.06	0.0004
MCC 004/04	30-35 CM	0.21	4.79	0.0154
MCC 004/05	40-45 CM	0.19	4.85	0.0123
MCC 004/06	50-55 CM	0.15	3.47	0.0136
MCC 004/07	75-80 CM	0.18	2.25	0.0080
MCC 005/01	0-5 CM	0.25	1.88	0.0004
MCC 005/02	10-15 CM	0.22	1.96	0.0006
MCC 005/03	20-25 CM	0.18	2.08	0.0007
MCC 005/04	30-35 CM	0.18	2.86	0.0017
MCC 005/05	40-45 CM	0.15	5.57	0.0150
MCC 005/06	50-55 CM	0.18	2.92	0.0115
MCC 005/07	75-80 CM	0.18	0.61	0.0002
MCC 005/08	100-105 CM	0.18	0.36	0.0003
MCC 006/01	0-5 CM	0.21	1.02	0.0003
MCC 006/02	10-15 CM	0.21	1.17	0.0005
MCC 006/03	20-25 CM	0.22	1.86	0.0065
MCC 006/04	30-35 CM	0.21	2.68	0.0133
MCC 006/05	40-45 CM	0.22	3.72	0.0158
MCC 006/06	50-55 CM	0.18	3.16	0.0146
MCC 006/07	75-80 CM	0.15	2.75	0.0077
MCC 006/08	100-105 CM	0.17	1.16	0.0025
MCC 007/01	0-5 CM	0.19	1.34	0.0004
MCC 007/02	10-15 CM	0.19	1.41	0.0003
MCC 007/03	20-25 CM	0.15	1.60	0.0005
MCC 007/04	30-35 CM	0.25	5.54	0.0167
MCC 007/05	40-45 CM	0.22	3.06	0.0136
MCC 007/06	50-55 CM	0.18	1.23	0.0012
MCC 007/07	75-80 CM	0.14	0.74	0.0003
MCC 008/01	0-5 CM	0.25	1.11	0.0004
MCC 008/02	10-15 CM	0.25	1.97	0.0008
MCC 008/03	20-25 CM	0.18	1.44	0.0015
MCC 008/04	30-35 CM	0.21	1.10	0.0005
MCC 008/05	40-45 CM	0.22	0.87	0.0004
MCC 008/06	50-55 CM	0.25	1.49	0.0006
MCC 008/07	75-80 CM	0.22	1.33	0.0007
MCC 008/08	100-105 CM	0.25	1.06	0.0003
MCC 009/01	0-5 CM	0.22	1.69	0.0024

Appendix 2-8

BaCl/ NH4Cl Extractable

SAMPLE No	DEPTH	Cr	Ni	Fe %
MCC 009/02	10-15 CM	0.18	0.87	0.0004
MCC 009/03	20-25 CM	0.19	1.59	0.0019
MCC 009/04	30-35 CM	0.21	2.88	0.0161
MCC 009/05	40-45 CM	0.19	1.07	0.0004
MCC 009/06	50-55 CM	0.18	1.05	0.0004
MCC 009/07	75-80 CM	0.15	0.79	0.0005
MCC 009/08	100-105 CM	0.19	0.27	0.0003
MCC 010/01	0-5 CM	0.18	2.49	0.0145
MCC 010/02	10-15 CM	0.15	2.71	0.0143
MCC 010/03	20-25 CM	0.18	2.31	0.0176
MCC 010/04	30-35 CM	0.18	2.18	0.0140
MCC 010/05	40-45 CM	0.15	1.40	0.0004
MCC 010/06	50-55 CM	0.21	1.10	0.0005
MCC 010/07	75-80 CM	0.18	1.31	0.0008
MCC 011/01	0-5 CM	0.22	1.39	0.0005
MCC 011/02	10-15 CM	0.22	0.70	0.0008
MCC 011/03	20-25 CM	0.18	1.57	0.0054
MCC 011/04	30-35 CM	0.15	2.33	0.0178
MCC 011/05	40-45 CM	0.18	1.03	0.0011
MCC 011/06	50-55 CM	0.21	0.77	0.0022
MCC 011/07	75-80 CM	0.18	0.87	0.0005
MCC 012/01	0-5 CM	0.22	1.16	0.0018
MCC 012/02	10-15 CM	0.28	1.93	0.0013
MCC 012/03	20-25 CM	0.25	1.23	0.0006
MCC 012/04	30-35 CM	0.22	1.40	0.0005
MCC 012/05	40-45 CM	0.18	1.04	0.0004
MCC 012/06	50-55 CM	0.18	1.12	0.0007
MCC 012/07	75-80 CM	0.18	1.21	0.0004

Appendix 2-9

Acetate Extrctable

SAMPLE No	DEPTH	Cd	Pb	Cu	Zn	Hg	Cr	Ni	Fe
MCC 001/01	0-5 CM	0.20	5.43	3.75	13.86	nd	0.11	1.40	0.0109
MCC 001/02	10-15 CM	0.24	5.51	2.11	15.59	nd	0.11	2.62	0.0004
MCC 001/03	20-25 CM	nd	3.15	0.89	8.63	nd	0.07	3.47	0.0029
MCC 001/04	30-35 CM	nd	0.58	0.36	1.96	nd	0.06	3.93	0.0037
MCC 001/05	40-45 CM	nd	0.54	0.34	2.14	nd	0.11	4.06	0.0030
MCC 001/06	50-55 CM	nd	0.13	0.09	1.36	nd	0.06	2.62	0.0101
MCC 001/07	75-80 CM	nd	0.10	0.09	1.12	nd	0.04	2.52	0.0045
MCC 001/08	100-105 CM	nd	0.20	0.12	1.22	nd	0.04	3.35	0.0094
MCC 001/09	125-130 CM	nd	0.31	0.41	3.11	nd	0.11	5.24	0.0023
MCC 002/01	0-5 CM	nd	4.06	2.82	20.95	nd	0.09	4.95	0.0059
MCC 002/02	10-15 CM	0.21	1.53	1.06	3.66	nd	0.09	4.24	0.0030
MCC 002/03	20-25 CM	0.20	3.95	2.19	133.05	nd	0.17	8.39	0.0203
MCC 002/04	30-35 CM	nd	1.09	0.55	1.46	nd	0.09	3.69	0.0025
MCC 002/05	40-45 CM	nd	0.80	0.38	1.76	nd	0.09	3.92	0.0147
MCC 002/06	50-55 CM	nd	0.17	0.11	1.76	nd	0.04	3.59	0.0034
MCC 002/07	75-80 CM	nd	0.17	0.22	1.68	nd	0.06	3.93	0.0016
MCC 002/08	100-105 CM	nd	0.09	0.07	1.07	nd	0.04	3.21	0.0013
MCC 003/01	0-5 CM	0.22	5.86	3.16	11.55	nd	0.11	4.47	0.0067
MCC 003/02	15-20 CM	0.13	6.55	1.83	11.32	nd	0.11	4.95	0.0143
MCC 003/03	25-30 CM	nd	2.68	0.79	2.65	nd	0.11	3.87	0.0138
MCC 003/04	30-35 CM	0.15	0.58	1.03	1.18	nd	0.06	3.51	0.0114
MCC 003/05	40-45 CM	nd	4.61	1.40	1.08	nd	0.04	3.38	0.0025
MCC 003/06	50-55 CM	nd	0.22	0.44	1.50	nd	0.08	3.59	0.0013
MCC 003/07	75-80 CM	nd	0.08	0.33	1.60	nd	0.06	3.46	0.0052
MCC 003/08	100-105 CM	nd	0.39	0.42	2.88	nd	0.16	6.55	0.0044
MCC 004/01	0-5 CM	0.20	3.47	1.15	19.90	nd	0.10	4.48	0.0294
MCC 004/02	10-15 CM	0.17	17.01	7.87	24.65	nd	0.09	4.15	0.0016
MCC 004/03	20-25 CM	nd	1.00	0.95	3.26	nd	0.06	3.46	0.0193
MCC 004/04	30-35 CM	nd	0.98	0.35	1.48	nd	0.11	2.54	0.0210
MCC 004/05	40-45 CM	nd	1.10	0.74	0.61	nd	0.09	2.46	0.0101
MCC 004/06	50-55 CM	0.24	0.24	0.30	0.94	nd	0.11	2.46	0.0038
MCC 004/07	75-80 CM	nd	0.24	0.08	1.56	nd	0.06	3.34	0.0067
MCC 005/01	0-5 CM	0.13	4.37	1.10	9.10	nd	0.07	3.31	0.0017
MCC 005/02	10-15 CM	nd	1.37	0.02	1.86	nd	0.09	2.80	0.0009
MCC 005/03	20-25 CM	nd	1.53	0.81	3.23	nd	0.13	3.51	0.0030
MCC 005/04	30-35 CM	nd	1.94	0.82	1.74	nd	0.11	3.74	0.0048
MCC 005/05	40-45 CM	nd	1.10	0.36	1.35	nd	0.13	2.86	0.0126
MCC 005/06	50-55 CM	nd	1.52	0.36	3.13	nd	0.13	2.40	0.0091
MCC 005/07	75-80 CM	nd	0.30	0.20	2.14	nd	0.11	3.09	0.0014
MCC 005/08	100-105 CM	nd	0.43	0.11	1.54	nd	0.20	4.78	0.0019
MCC 006/01	0-5 CM	0.34	14.06	3.36	17.58	nd	0.06	3.80	0.0013
MCC 006/02	10-15 CM	nd	3.09	0.61	3.09	nd	0.10	3.42	0.0022
MCC 006/03	20-25 CM	nd	3.61	0.90	2.94	nd	0.13	3.60	0.0150
MCC 006/04	30-35 CM	nd	1.57	2.90	3.06	nd	0.11	2.99	0.0241
MCC 006/05	40-45 CM	nd	2.37	1.12	2.32	nd	0.13	2.60	0.0170
MCC 006/06	50-55 CM	0.07	0.42	0.50	1.34	nd	0.25	3.34	0.0024
MCC 006/07	75-80 CM	nd	0.10	0.20	0.93	nd	0.11	1.92	0.0044
MCC 006/08	100-105 CM	nd	0.23	0.28	1.63	nd	0.17	2.72	0.0012
MCC 007/01	0-5 CM	nd	0.65	0.70	5.11	nd	0.11	2.72	0.0096
MCC 007/02	10-15 CM	0.46	0.25	0.23	1.42	nd	0.13	2.14	0.0021
MCC 007/03	20-25 CM	nd	0.39	1.61	1.35	nd	0.13	2.71	0.0062
MCC 007/04	30-35 CM	nd	0.16	0.92	0.49	nd	0.13	2.09	0.0109
MCC 007/05	40-45 CM	nd	0.18	1.24	6.52	nd	0.13	2.50	0.0016
MCC 007/06	50-55 CM	nd	0.35	1.24	1.81	nd	0.16	2.40	0.0104
MCC 007/07	75-80 CM	nd	0.53	0.93	1.84	nd	0.15	2.33	0.0054
MCC 008/01	0-5 CM	nd	1.89	0.21	4.84	nd	0.13	1.89	0.0013
MCC 008/02	10-15 CM	nd	1.59	0.19	19.15	0.07	0.11	2.99	0.0042
MCC 008/03	20-25 CM	nd	0.75	0.80	8.10	nd	0.13	4.80	0.0204
MCC 008/04	30-35 CM	nd	0.27	0.55	1.36	nd	0.33	2.24	0.0030
MCC 008/05	40-45 CM	nd	0.38	0.43	1.77	nd	0.13	2.67	0.0108
MCC 008/06	50-55 CM	0.02	0.61	1.49	1.84	nd	0.16	2.58	0.0054
MCC 008/07	75-80 CM	nd	0.48	0.86	3.22	nd	0.16	2.14	0.0070
MCC 008/08	100-105 CM	nd	0.23	0.63	1.83	nd	0.13	2.89	0.0048
MCC 009/01	0-5 CM	0.02	0.79	0.88	3.71	nd	0.16	2.05	0.0067

Appendix 2-10

Acetate Extrctable

SAMPLE No	DEPTH	Cd	Pb	Cu	Zn	Hg	Cr	Ni	Fe
MCC 009/02	10-15 CM	nd	0.61	0.33	2.61	0.00	0.13	2.21	0.0018
MCC 009/03	20-25 CM	0.02	0.74	1.43	2.25	0.48	0.13	2.13	0.0075
MCC 009/04	30-35 CM	nd	0.44	2.00	2.06	0.01	0.13	2.15	0.0133
MCC 009/05	40-45 CM	nd	0.47	0.78	1.07	0.00	0.16	1.97	0.0042
MCC 009/06	50-55 CM	nd	0.92	1.00	1.40	0.00	0.13	2.58	0.0072
MCC 009/07	75-80 CM	nd	0.96	1.26	1.14	0.00	0.16	3.53	0.0046
MCC 009/08	100-105 CM	0.02	0.53	0.58	2.55	0.00	0.45	3.09	0.0042
MCC 010/01	0-5 CM	nd	0.40	0.35	2.89	0.39	0.18	1.84	0.0155
MCC 010/02	10-15 CM	nd	0.36	0.07	2.10	0.55	0.16	2.05	0.0087
MCC 010/03	20-25 CM	nd	0.44	0.89	1.58	0.68	0.09	2.22	0.0215
MCC 010/04	30-35 CM	nd	0.69	2.27	3.28	0.00	0.13	2.35	0.0205
MCC 010/05	40-45 CM	0.12	0.44	0.79	1.40	0.00	0.16	2.49	0.0025
MCC 010/06	50-55 CM	nd	0.05	0.94	0.48	0.00	0.15	2.42	0.0029
MCC 010/07	75-80 CM	nd	0.52	3.26	0.68	0.00	0.20	2.58	0.0051
MCC 011/01	0-5 CM	nd	1.62	0.51	7.91	0.00	0.13	2.47	0.0023
MCC 011/02	10-15 CM	nd	1.05	0.24	4.71	0.00	0.11	2.30	0.0062
MCC 011/03	20-25 CM	1.19	2.01	2.12	2.01	0.00	0.13	2.10	0.0097
MCC 011/04	30-35 CM	0.03	0.48	0.81	0.91	0.00	0.18	1.86	0.0098
MCC 011/05	40-45 CM	nd	0.33	0.39	0.39	0.00	0.15	1.82	0.0033
MCC 011/06	50-55 CM	nd	0.45	0.54	1.02	0.00	0.24	2.26	0.0029
MCC 011/07	75-80 CM	nd	0.48	1.05	0.76	0.00	0.18	2.02	0.0035
MCC 012/01	0-5 CM	nd	1.73	0.16	14.11	0.00	0.18	1.87	0.0021
MCC 012/02	10-15 CM	0.38	1.41	0.34	3.15	0.00	0.20	1.65	0.0013
MCC 012/03	20-25 CM	nd	1.55	0.93	1.83	0.01	0.23	1.85	0.0032
MCC 012/04	30-35 CM	nd	0.48	0.54	0.72	0.00	0.18	2.03	0.0060
MCC 012/05	40-45 CM	nd	0.50	0.82	0.64	0.00	0.11	1.73	0.0067
MCC 012/06	50-55 CM	nd	0.28	1.32	1.56	0.01	0.09	1.28	0.0070
MCC 012/07	75-80 CM	0.35	0.51	5.38	10.39	0.00	0.15	1.36	0.0079

Appendix 2-11

Dithionite Extractable

SAMPLE No	DEPTH	Cd	Pb	Cu	Zn	Hg	Cr	Ni	Fe
MCC 001/01	0-5 CM	nd	7.62	5.15	9.84	0.75	0.24	4.06	0.14
MCC 001/02	10-15 CM	0.15	8.83	18.81	33.90	0.01	0.32	6.36	0.09
MCC 001/03	20-25 CM	nd	7.05	8.43	20.33	0.27	0.32	5.59	0.11
MCC 001/04	30-35 CM	nd	8.06	3.83	47.73	16.78	0.35	12.34	0.17
MCC 001/05	40-45 CM	nd	5.83	1.94	4.36	0.09	0.30	7.44	0.16
MCC 001/06	50-55 CM	nd	6.15	1.04	2.54	0.06	0.28	4.66	0.20
MCC 001/07	75-80 CM	nd	5.91	0.95	1.62	nd	0.22	4.30	0.13
MCC 001/08	100-105 CM	nd	6.30	1.01	2.33	nd	0.17	4.78	0.16
MCC 001/09	125-130 CM	nd	5.94	1.72	2.63	0.23	0.16	4.81	0.10
MCC 002/01	0-5 CM	nd	6.67	161.58	170.33	8.40	0.30	6.01	0.52
MCC 002/02	10-15 CM	nd	6.26	4.46	9.97	nd	0.26	4.88	0.07
MCC 002/03	20-25 CM	nd	7.44	61.78	123.81	0.07	0.71	12.82	0.44
MCC 002/04	30-35 CM	nd	5.67	3.31	4.74	0.53	0.23	5.16	0.07
MCC 002/05	40-45 CM	nd	5.94	2.65	2.46	3.14	0.32	4.54	0.12
MCC 002/06	50-55 CM	nd	6.26	1.19	2.24	nd	0.25	5.32	0.18
MCC 002/07	75-80 CM	nd	5.87	1.86	3.87	nd	0.22	5.31	0.09
MCC 002/08	100-105 CM	nd	6.01	2.46	2.84	nd	0.19	5.16	0.10
MCC 003/01	0-5 CM	nd	7.14	7.81	15.93	0.14	0.27	4.86	0.15
MCC 003/02	15-20 CM	nd	6.50	9.06	9.15	2.75	0.51	5.29	0.15
MCC 003/03	25-30 CM	nd	5.21	5.05	4.28	0.66	0.41	3.96	0.11
MCC 003/04	30-35 CM	nd	5.32	2.50	2.33	0.10	0.34	4.09	0.11
MCC 003/05	40-45 CM	0.23	35.91	15.45	20.90	1.92	0.31	5.53	0.11
MCC 003/06	50-55 CM	nd	5.84	3.61	4.17	0.09	0.27	5.10	0.08
MCC 003/07	75-80 CM	nd	7.03	3.30	3.48	0.00	0.30	5.57	0.08
MCC 003/08	100-105 CM	nd	6.61	2.45	4.24	0.04	0.26	5.60	0.15
MCC 004/01	0-5 CM	nd	7.40	3.60	16.01	0.09	0.23	3.70	0.16
MCC 004/02	10-15 CM	0.14	11.99	99.26	37.34	21.76	0.39	5.60	0.18
MCC 004/03	20-25 CM	nd	6.85	2.26	8.02	0.10	0.39	6.29	0.50
MCC 004/04	30-35 CM	0.71	7.68	36.82	30.29	10.96	0.68	7.35	0.21
MCC 004/05	40-45 CM	nd	6.51	3.40	3.53	0.05	0.39	4.67	0.11
MCC 004/06	50-55 CM	nd	6.33	2.21	2.24	0.03	0.37	4.40	0.10
MCC 004/07	75-80 CM	nd	6.28	1.27	1.57	0.08	0.32	4.51	0.13
MCC 005/01	0-5 CM	nd	6.89	10.78	18.28	0.39	0.34	5.51	0.04
MCC 005/02	10-15 CM	nd	6.68	4.01	10.10	0.38	0.39	4.67	0.03
MCC 005/03	20-25 CM	nd	6.97	2.19	9.28	0.13	0.39	5.48	0.14
MCC 005/04	30-35 CM	nd	6.42	1.56	3.76	0.13	0.42	6.30	0.21
MCC 005/05	40-45 CM	nd	6.62	2.04	3.54	0.18	0.34	4.60	0.14
MCC 005/06	50-55 CM	nd	6.01	3.61	2.81	0.08	0.45	4.20	0.11
MCC 005/07	75-80 CM	nd	6.10	1.25	2.85	nd	0.25	4.53	0.08
MCC 005/08	100-105 CM	nd	7.01	2.05	3.70	0.02	0.32	5.10	0.11
MCC 006/01	0-5 CM	nd	7.09	18.33	28.17	0.14	0.34	5.00	0.07
MCC 006/02	10-15 CM	nd	5.81	4.53	12.76	0.31	0.45	5.24	0.10
MCC 006/03	20-25 CM	nd	9.97	6.29	10.23	0.27	0.42	5.17	0.16
MCC 006/04	30-35 CM	nd	5.89	2.46	2.89	0.11	0.42	4.46	0.27
MCC 006/05	40-45 CM	nd	5.43	2.50	3.01	0.17	0.51	4.18	0.23
MCC 006/06	50-55 CM	nd	6.12	1.62	3.42	0.06	0.44	4.74	0.16
MCC 006/07	75-80 CM	nd	5.55	1.29	2.03	nd	0.33	3.43	0.09
MCC 006/08	100-105 CM	nd	5.80	1.98	3.74	0.05	0.23	4.57	0.09
MCC 007/01	0-5 CM	nd	6.38	3.01	10.23	0.02	0.22	3.04	0.18
MCC 007/02	10-15 CM	0.32	6.15	2.10	8.01	nd	0.39	5.18	0.20
MCC 007/03	20-25 CM	nd	5.17	2.58	4.08	0.12	0.39	5.20	0.51
MCC 007/04	30-35 CM	nd	5.21	0.97	1.35	nd	0.47	3.50	0.46
MCC 007/05	40-45 CM	nd	4.64	1.04	1.65	nd	0.33	2.85	0.29
MCC 007/06	50-55 CM	nd	4.63	0.98	4.28	nd	0.54	4.01	0.13
MCC 007/07	75-80 CM	nd	5.25	1.56	7.25	nd	0.36	5.04	0.21
MCC 008/01	0-5 CM	nd	5.16	4.37	15.74	0.19	0.26	4.55	0.06
MCC 008/02	10-15 CM	nd	6.18	4.32	46.54	0.20	0.35	8.11	0.17
MCC 008/03	20-25 CM	nd	4.48	0.95	15.38	nd	0.81	10.19	0.33
MCC 008/04	30-35 CM	nd	4.65	0.85	4.18	nd	0.34	5.15	0.28
MCC 008/05	40-45 CM	nd	4.61	1.03	4.40	nd	0.42	5.69	0.17
MCC 008/06	50-55 CM	nd	4.29	0.93	4.27	nd	0.38	4.88	0.24
MCC 008/07	75-80 CM	nd	4.51	1.58	13.18	nd	0.25	3.97	0.12
MCC 008/08	100-105 CM	nd	5.82	4.31	4.79	0.05	0.28	6.95	0.19
MCC 009/01	0-5 CM	nd	5.84	2.16	7.62	0.08	0.32	4.63	0.18

Appendix 2-12

Dithionite Extractable

SAMPLE No	DEPTH	Cd	Pb	Cu	Zn	Hg	Cr	Ni	Fe
MCC 009/02	10-15 CM	nd	5.43	1.56	11.25	nd	0.33	5.62	0.11
MCC 009/03	20-25 CM	nd	4.66	1.26	11.21	nd	0.42	4.77	0.18
MCC 009/04	30-35 CM	nd	4.18	0.80	1.91	nd	0.39	3.51	0.32
MCC 009/05	40-45 CM	nd	4.86	0.89	7.58	nd	0.30	4.81	0.17
MCC 009/06	50-55 CM	nd	5.10	1.09	4.95	nd	0.26	5.21	0.19
MCC 009/07	75-80 CM	nd	5.46	1.15	3.38	0.10	0.26	4.51	0.16
MCC 009/08	100-105 CM	nd	6.00	4.27	20.97	0.06	0.25	7.14	0.19
MCC 010/01	0-5 CM	nd	6.27	2.70	4.12	0.10	0.52	4.81	0.25
MCC 010/02	10-15 CM	nd	5.66	1.42	2.74	0.13	0.42	5.03	0.23
MCC 010/03	20-25 CM	nd	5.12	0.88	2.63	0.04	0.49	4.66	0.35
MCC 010/04	30-35 CM	nd	4.86	2.20	16.53	nd	0.63	7.44	0.25
MCC 010/05	40-45 CM	nd	5.26	0.72	9.06	0.10	0.44	5.62	0.21
MCC 010/06	50-55 CM	nd	5.60	0.90	7.92	0.03	0.41	5.71	0.21
MCC 010/07	75-80 CM	nd	4.79	6.90	1.89	0.08	0.26	4.57	0.21
MCC 011/01	0-5 CM	nd	6.04	3.68	18.99	0.32	0.36	5.49	0.12
MCC 011/02	10-15 CM	nd	5.75	2.80	10.18	0.03	0.28	5.20	0.14
MCC 011/03	20-25 CM	nd	5.38	0.92	4.12	0.06	0.50	5.41	0.24
MCC 011/04	30-35 CM	nd	5.17	1.21	3.65	nd	0.41	4.38	0.35
MCC 011/05	40-45 CM	nd	5.20	0.71	4.69	nd	0.38	4.03	0.17
MCC 011/06	50-55 CM	nd	4.69	1.02	4.49	0.14	0.38	3.55	0.13
MCC 011/07	75-80 CM	nd	4.29	5.09	2.31	0.03	0.26	2.14	0.03
MCC 012/01	0-5 CM	nd	6.90	6.97	25.73	0.06	0.36	2.11	0.15
MCC 012/02	10-15 CM	nd	5.23	4.93	8.94	0.14	0.35	5.26	0.08
MCC 012/03	20-25 CM	nd	4.82	1.04	15.69	0.05	0.54	7.45	0.12
MCC 012/04	30-35 CM	nd	4.46	1.09	14.42	0.03	0.40	4.73	0.11
MCC 012/05	40-45 CM	nd	3.94	1.49	8.13	0.06	0.41	6.89	0.15
MCC 012/06	50-55 CM	nd	4.42	0.50	7.59	nd	0.55	5.98	0.39
MCC 012/07	75-80 CM	nd	4.40	3.81	36.55	0.10	0.43	2.87	0.21

Appendix 2-13

Aquaregia Extractable

SAMPLE No	DEPTH	Cd	Pb	Cu	Zn	Hg	Cr	Ni	Fe
MCC 001/01	0-5 CM	nd	26.40	13.07	30.24	0.53	1.75	6.58	1.20
MCC 001/02	10-15 CM	nd	44.53	34.44	98.23	0.55	1.65	19.67	1.36
MCC 001/03	20-25 CM	nd	45.54	23.41	78.24	1.26	2.82	17.52	1.62
MCC 001/04	30-35 CM	nd	27.12	24.55	64.61	0.98	3.69	22.36	2.53
MCC 001/05	40-45 CM	nd	10.63	16.12	35.90	0.73	2.88	16.28	2.07
MCC 001/06	50-55 CM	nd	2.72	15.05	27.02	0.51	1.30	8.95	1.91
MCC 001/07	75-80 CM	nd	3.64	5.14	18.92	0.69	1.53	9.07	1.13
MCC 001/08	100-105 CM	nd	5.96	8.09	25.54	0.74	1.82	12.09	1.40
MCC 001/09	125-130 CM	nd	4.85	2.72	17.25	0.71	2.34	8.89	1.29
MCC 002/01	0-5 CM	nd	43.69	30.22	39.11	0.18	0.98	11.29	1.03
MCC 002/02	10-15 CM	nd	27.46	8.29	78.37	nd	3.00	21.86	1.42
MCC 002/03	20-25 CM	0.54	23.61	38.84	131.49	0.95	4.28	30.97	3.47
MCC 002/04	30-35 CM	0.34	10.45	19.60	49.24	0.72	4.72	31.68	2.31
MCC 002/05	40-45 CM	0.27	9.34	20.70	34.32	0.14	2.68	14.44	2.56
MCC 002/06	50-55 CM	0.35	3.37	10.83	32.49	nd	1.92	13.19	1.59
MCC 002/07	75-80 CM	0.22	4.04	3.95	25.06	0.11	1.52	11.79	1.39
MCC 002/08	100-105 CM	0.36	5.06	7.19	27.29	4.67	1.89	12.17	1.48
MCC 003/01	0-5 CM	0.34	19.42	15.58	41.26	7.20	2.41	15.08	1.41
MCC 003/02	15-20 CM	0.31	25.03	33.79	37.51	3.31	2.93	16.62	2.77
MCC 003/03	25-30 CM	0.25	11.39	15.27	33.55	3.25	2.66	15.58	1.96
MCC 003/04	30-35 CM	0.21	4.69	9.74	25.26	7.67	2.29	13.58	1.82
MCC 003/05	40-45 CM	0.45	40.74	20.62	29.65	1.29	1.68	12.20	1.13
MCC 003/06	50-55 CM	0.11	7.02	8.72	25.78	2.55	1.80	15.20	1.38
MCC 003/07	75-80 CM	0.19	3.83	5.47	25.22	1.02	1.37	14.79	1.41
MCC 003/08	100-105 CM	0.17	5.62	12.01	37.42	1.14	3.18	21.66	2.42
MCC 004/01	0-5 CM	0.27	15.63	7.37	26.37	4.67	0.92	7.46	0.72
MCC 004/02	10-15 CM	0.72	89.47	79.59	113.15	2.25	2.16	12.55	1.18
MCC 004/03	20-25 CM	0.51	13.53	26.45	54.23	1.10	2.87	14.56	3.24
MCC 004/04	30-35 CM	0.33	8.26	20.68	23.40	1.62	1.58	8.32	1.86
MCC 004/05	40-45 CM	0.30	5.94	20.61	23.12	0.92	2.11	10.96	1.87
MCC 004/06	50-55 CM	0.24	3.54	12.96	19.89	0.86	1.63	7.51	1.77
MCC 004/07	75-80 CM	0.18	4.55	13.29	24.14	0.82	2.69	13.13	1.88
MCC 005/01	0-5 CM	nd	38.43	54.77	44.93	0.56	0.95	16.84	0.93
MCC 005/02	10-15 CM	0.39	20.79	21.96	65.10	0.32	2.60	17.20	1.05
MCC 005/03	20-25 CM	0.29	32.47	35.00	55.12	0.40	3.72	24.81	2.59
MCC 005/04	30-35 CM	0.23	12.90	35.96	43.43	nd	3.32	26.38	2.84
MCC 005/05	40-45 CM	0.29	12.87	30.66	29.32	2.36	2.10	15.55	3.07
MCC 005/06	50-55 CM	0.23	10.50	20.37	31.36	2.13	2.63	14.65	1.99
MCC 005/07	75-80 CM	0.26	4.74	12.87	31.88	1.09	1.84	10.48	1.42
MCC 005/08	100-105 CM	0.24	4.20	10.16	27.21	1.07	1.55	11.59	1.44
MCC 006/01	0-5 CM	nd	51.85	80.52	68.99	0.58	2.49	16.42	1.36
MCC 006/02	10-15 CM	nd	20.56	19.43	60.00	0.16	3.46	20.25	2.07
MCC 006/03	20-25 CM	0.21	24.37	22.91	44.80	0.38	2.85	15.94	2.34
MCC 006/04	30-35 CM	nd	10.40	24.55	38.15	0.19	2.82	18.63	2.84
MCC 006/05	40-45 CM	0.21	14.62	27.46	36.12	0.19	2.59	11.83	2.71
MCC 006/06	50-55 CM	0.33	3.89	27.34	67.23	0.12	1.73	11.96	2.43
MCC 006/07	75-80 CM	1.14	4.97	6.94	23.93	0.28	1.47	9.06	1.62
MCC 006/08	100-105 CM	0.41	5.98	6.04	29.20	0.23	1.12	13.16	1.34
MCC 007/01	0-5 CM	0.26	13.51	4.25	13.17	0.58	0.41	0.94	0.98
MCC 007/02	10-15 CM	1.29	16.07	23.96	86.06	0.31	2.42	36.35	2.94
MCC 007/03	20-25 CM	nd	9.84	14.10	53.71	0.10	2.30	32.36	2.78
MCC 007/04	30-35 CM	nd	2.19	13.74	19.46	0.40	1.39	10.72	2.43
MCC 007/05	40-45 CM	0.27	2.05	10.31	24.44	0.07	1.39	9.67	1.66
MCC 007/06	50-55 CM	0.26	4.12	11.34	27.75	0.13	1.66	13.67	1.69
MCC 007/07	75-80 CM	0.28	4.72	8.25	22.99	0.09	1.27	10.50	1.36
MCC 008/01	0-5 CM	nd	19.11	19.98	44.51	0.02	1.24	12.22	1.04
MCC 008/02	10-15 CM	nd	24.04	34.35	77.51	0.15	1.71	14.45	1.81
MCC 008/03	20-25 CM	nd	0.00	35.85	54.63	0.52	2.84	30.68	2.70
MCC 008/04	30-35 CM	nd	0.00	28.95	43.70	nd	2.71	36.58	3.01
MCC 008/05	40-45 CM	nd	1.92	28.88	35.75	nd	2.06	20.91	2.02
MCC 008/06	50-55 CM	nd	0.00	23.64	35.63	nd	1.88	20.45	2.28
MCC 008/07	75-80 CM	0.51	4.29	12.52	71.11	0.13	1.46	12.23	1.53
MCC 008/08	100-105 CM	nd	11.07	21.96	50.50	0.22	2.28	33.22	2.43
MCC 009/01	0-5 CM	nd	8.58	19.37	35.11	nd	1.62	12.26	1.68

Appendix 2-14

Aquaregia Extractable

SAMPLE No	DEPTH	Cd	Pb	Cu	Zn	Hg	Cr	Ni	Fe
MCC 009/02	10-15 CM	nd	14.39	17.85	43.92	nd	2.45	24.80	2.07
MCC 009/03	20-25 CM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MCC 009/04	30-35 CM	nd	nd	23.01	36.13	nd	2.15	22.11	2.64
MCC 009/05	40-45 CM	nd	5.97	14.80	30.39	0.14	1.58	16.64	1.63
MCC 009/06	50-55 CM	nd	5.71	16.11	27.78	0.14	1.62	12.67	1.51
MCC 009/07	75-80 CM	nd	4.53	13.08	23.72	0.39	1.19	11.06	1.41
MCC 009/08	100-105 CM	0.53	10.77	29.82	70.59	0.02	2.26	27.34	2.52
MCC 010/01	0-5 CM	nd	13.89	24.66	40.69	0.35	2.24	24.58	2.59
MCC 010/02	10-15 CM	0.43	6.69	21.65	32.35	0.48	1.57	15.04	2.58
MCC 010/03	20-25 CM	0.22	1.76	20.98	49.62	0.56	2.11	30.56	2.21
MCC 010/04	30-35 CM	0.50	1.14	18.84	46.96	0.54	1.66	16.51	1.95
MCC 010/05	40-45 CM	0.32	3.72	15.80	41.45	0.56	1.90	25.08	2.09
MCC 010/06	50-55 CM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MCC 010/07	75-80 CM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MCC 011/01	0-5 CM	0.34	21.22	12.44	61.14	nd	1.39	14.53	1.47
MCC 011/02	10-15 CM	nd	9.88	18.91	33.17	nd	1.25	6.85	1.26
MCC 011/03	20-25 CM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MCC 011/04	30-35 CM	nd	0.74	12.38	21.93	0.56	1.21	8.29	1.38
MCC 011/05	40-45 CM	nd	4.75	9.90	30.25	0.61	1.44	15.71	1.63
MCC 011/06	50-55 CM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MCC 011/07	75-80 CM	nd	1.16	9.80	11.24	0.35	1.28	1.81	0.29
MCC 012/01	0-5 CM	0.34	10.63	23.39	42.03	0.44	0.85	8.49	0.67
MCC 012/02	10-15 CM	nd	6.46	26.82	46.44	0.45	1.19	12.98	0.74
MCC 012/03	20-25 CM	nd	6.33	22.07	64.16	0.58	1.88	21.88	1.57
MCC 012/04	30-35 CM	nd	1.30	21.60	33.72	0.33	1.96	20.25	2.71
MCC 012/05	40-45 CM	nd	0.48	18.30	59.02	0.37	1.99	21.23	1.95
MCC 012/06	50-55 CM	nd	1.61	19.44	34.25	0.35	1.82	18.64	2.84
MCC 012/07	75-80 CM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix 2-15

Total Extractable

SAMPLE No	DEPTH	Cd	Pb	Cu	Zn	Hg	Cr	Ni	Fe
MCC 001/01	0-5 CM	0.20	41.46	22.68	55.05	1.41	2.31	12.30	1.35
MCC 001/02	10-15 CM	0.39	62.00	56.94	149.86	0.56	2.26	29.80	1.45
MCC 001/03	20-25 CM	nd	58.77	33.32	108.65	1.53	3.42	28.00	1.73
MCC 001/04	30-35 CM	nd	37.71	29.09	115.67	17.76	4.25	39.61	2.70
MCC 001/05	40-45 CM	nd	18.74	18.81	43.40	0.81	3.46	28.79	2.23
MCC 001/06	50-55 CM	nd	11.10	16.31	41.94	0.56	1.84	19.03	2.14
MCC 001/07	75-80 CM	nd	11.53	6.37	29.04	0.69	1.96	17.16	1.28
MCC 001/08	100-105 CM	nd	14.23	9.42	35.16	0.74	2.21	21.42	1.58
MCC 001/09	125-130 CM	nd	12.67	4.87	23.57	0.94	2.83	19.38	1.40
MCC 002/01	0-5 CM	nd	57.02	195.35	231.59	8.57	1.52	23.39	1.56
MCC 002/02	10-15 CM	0.21	37.96	14.22	93.22	nd	3.57	31.85	1.50
MCC 002/03	20-25 CM	0.74	38.44	103.79	767.54	1.02	5.37	56.63	3.93
MCC 002/04	30-35 CM	0.34	19.62	23.79	56.27	1.25	5.24	41.38	2.38
MCC 002/05	40-45 CM	0.27	18.80	24.08	53.66	3.28	3.33	26.43	2.70
MCC 002/06	50-55 CM	0.35	11.74	12.17	40.55	nd	2.46	23.33	1.78
MCC 002/07	75-80 CM	0.22	11.71	6.07	31.23	0.11	1.98	21.45	1.48
MCC 002/08	100-105 CM	0.36	12.82	9.74	31.77	4.67	2.31	21.14	1.58
MCC 003/01	0-5 CM	0.55	34.31	26.81	69.81	7.34	3.00	25.26	1.57
MCC 003/02	15-20 CM	0.44	47.49	51.01	82.77	6.06	3.74	31.21	2.95
MCC 003/03	25-30 CM	0.25	22.22	22.59	58.66	3.91	3.36	26.80	2.09
MCC 003/04	30-35 CM	0.36	12.75	13.75	29.96	7.78	2.87	24.54	1.96
MCC 003/05	40-45 CM	0.67	83.18	37.88	52.77	3.21	2.21	22.15	1.23
MCC 003/06	50-55 CM	0.11	14.69	12.87	31.96	2.65	2.33	24.65	1.46
MCC 003/07	75-80 CM	0.19	12.78	9.13	30.88	1.02	1.92	24.62	1.50
MCC 003/08	100-105 CM	0.17	14.44	15.22	45.67	1.19	3.79	34.78	2.57
MCC 004/01	0-5 CM	0.47	28.82	12.87	63.69	4.76	1.43	16.70	0.91
MCC 004/02	10-15 CM	1.02	126.17	195.91	238.22	24.01	2.90	24.65	1.36
MCC 004/03	20-25 CM	0.51	23.73	30.24	66.78	1.21	3.51	25.37	3.76
MCC 004/04	30-35 CM	1.04	19.44	58.41	68.62	12.59	2.58	23.00	2.11
MCC 004/05	40-45 CM	0.30	17.35	25.56	40.83	0.97	2.77	22.95	2.00
MCC 004/06	50-55 CM	0.48	12.33	15.74	36.00	0.89	2.27	17.84	1.89
MCC 004/07	75-80 CM	0.18	13.09	14.82	32.30	0.90	3.25	23.23	2.02
MCC 005/01	0-5 CM	0.13	53.37	68.09	76.01	0.95	1.60	27.54	0.97
MCC 005/02	10-15 CM	0.39	31.72	26.73	78.40	0.69	3.29	26.64	1.09
MCC 005/03	20-25 CM	0.29	43.51	38.42	69.06	0.53	4.42	35.87	2.73
MCC 005/04	30-35 CM	0.23	24.10	39.22	51.88	0.14	4.03	39.29	3.06
MCC 005/05	40-45 CM	0.29	24.14	33.92	51.87	2.54	2.72	28.58	3.24
MCC 005/06	50-55 CM	0.23	21.60	25.59	50.22	2.22	3.39	24.17	2.12
MCC 005/07	75-80 CM	0.26	13.20	14.46	37.78	1.09	2.38	18.71	1.51
MCC 005/08	100-105 CM	0.24	13.72	12.59	33.34	1.10	2.25	21.82	1.55
MCC 006/01	0-5 CM	0.34	77.41	104.33	125.65	0.72	3.10	26.25	1.43
MCC 006/02	10-15 CM	nd	32.28	25.12	79.40	0.47	4.22	30.08	2.17
MCC 006/03	20-25 CM	0.21	41.06	30.76	79.02	0.66	3.62	26.57	2.53
MCC 006/04	30-35 CM	nd	20.74	30.54	54.64	0.29	3.56	28.76	3.14
MCC 006/05	40-45 CM	0.21	26.70	31.73	56.25	0.38	3.44	22.33	2.97
MCC 006/06	50-55 CM	0.40	13.28	30.03	102.00	0.18	2.60	23.19	2.61
MCC 006/07	75-80 CM	1.14	12.68	8.54	32.39	0.28	2.05	17.15	1.72
MCC 006/08	100-105 CM	0.41	13.98	8.41	35.09	0.27	1.70	21.62	1.43
MCC 007/01	0-5 CM	0.26	22.91	8.31	29.15	0.59	0.92	8.04	1.17
MCC 007/02	10-15 CM	2.07	24.82	26.87	96.30	0.33	3.13	45.08	3.14
MCC 007/03	20-25 CM	nd	17.37	18.71	60.81	0.22	2.97	41.87	3.30
MCC 007/04	30-35 CM	nd	9.99	16.27	27.82	0.40	2.24	21.85	2.92
MCC 007/05	40-45 CM	0.27	9.21	13.09	43.26	0.07	2.08	18.07	1.97
MCC 007/06	50-55 CM	0.26	10.91	13.98	36.86	0.13	2.54	21.31	1.83
MCC 007/07	75-80 CM	0.28	12.20	11.00	32.72	0.09	1.92	18.61	1.57
MCC 008/01	0-5 CM	nd	29.32	25.05	66.64	0.28	1.87	19.77	1.10
MCC 008/02	10-15 CM	nd	35.09	39.45	160.34	0.35	2.43	27.52	1.98
MCC 008/03	20-25 CM	nd	7.36	38.60	80.43	0.52	3.96	47.12	3.05
MCC 008/04	30-35 CM	nd	7.18	30.76	50.66	nd	3.39	45.07	3.29
MCC 008/05	40-45 CM	nd	9.22	30.69	42.77	nd	2.83	30.14	2.19
MCC 008/06	50-55 CM	0.02	7.23	26.40	44.20	nd	2.67	29.39	2.53
MCC 008/07	75-80 CM	0.51	11.37	15.08	89.00	0.13	2.08	19.66	1.66
MCC 008/08	100-105 CM	nd	19.09	26.94	57.61	0.27	2.95	44.12	2.62
MCC 009/01	0-5 CM	0.02	17.57	22.76	65.62	0.08	2.32	20.63	1.87

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Total Extractable

SAMPLE No	DEPTH	Cd	Pb	Cu	Zn	Hg	Cr	Ni	Fe
MCC 009/02	10-15 CM	nd	22.50	20.16	58.96	0.48	3.10	33.49	2.19
MCC 009/03	20-25 CM	0.02	7.49	3.11	20.44	0.01	0.74	8.50	0.19
MCC 009/04	30-35 CM	nd	7.01	26.29	51.42	nd	2.88	30.64	2.99
MCC 009/05	40-45 CM	nd	13.28	16.98	40.16	0.14	2.22	24.48	1.81
MCC 009/06	50-55 CM	nd	13.55	18.54	35.32	0.14	2.20	21.52	1.71
MCC 009/07	75-80 CM	nd	12.89	15.83	29.26	0.49	1.76	19.89	1.58
MCC 009/08	100-105 CM	0.55	19.27	34.78	94.67	0.47	3.15	37.84	2.71
MCC 010/01	0-5 CM	nd	23.54	28.59	91.51	1.00	3.12	33.73	2.88
MCC 010/02	10-15 CM	0.43	15.60	23.49	64.69	1.30	2.30	24.83	2.83
MCC 010/03	20-25 CM	0.22	9.79	23.33	65.63	0.60	2.87	39.75	2.60
MCC 010/04	30-35 CM	0.50	9.24	23.80	81.93	0.54	2.61	28.48	2.24
MCC 010/05	40-45 CM	0.44	11.62	17.65	53.27	0.65	2.65	34.58	2.31
MCC 010/06	50-55 CM	0.00	7.91	3.00	9.69	0.03	0.77	9.22	0.21
MCC 010/07	75-80 CM	0.00	7.51	10.66	3.96	0.09	0.65	8.47	0.27
MCC 011/01	0-5 CM	0.34	31.71	16.98	92.25	0.32	2.10	23.88	1.59
MCC 011/02	10-15 CM	nd	19.51	22.29	49.21	0.04	1.85	15.05	1.40
MCC 011/03	20-25 CM	1.19	9.95	3.53	14.90	0.06	0.81	9.07	0.25
MCC 011/04	30-35 CM	0.03	8.73	14.98	38.90	0.56	1.95	16.86	1.75
MCC 011/05	40-45 CM	nd	12.32	11.49	55.81	0.61	2.15	22.60	1.80
MCC 011/06	50-55 CM	0.00	7.43	1.97	6.46	0.14	0.93	6.58	0.13
MCC 011/07	75-80 CM	nd	8.12	16.13	15.31	0.39	1.90	6.84	0.33
MCC 012/01	0-5 CM	0.34	22.68	31.65	95.42	0.52	1.61	13.63	0.83
MCC 012/02	10-15 CM	0.38	16.71	32.58	61.46	0.60	2.02	21.82	0.82
MCC 012/03	20-25 CM	nd	16.09	24.62	84.68	0.64	2.91	32.42	1.70
MCC 012/04	30-35 CM	nd	9.22	23.88	50.44	0.36	2.76	28.41	2.83
MCC 012/05	40-45 CM	nd	7.60	20.95	68.72	0.44	2.70	30.89	2.11
MCC 012/06	50-55 CM	nd	9.13	21.53	45.54	0.35	2.64	27.03	3.24
MCC 012/07	75-80 CM	0.35	7.34	9.63	49.57	0.10	0.76	5.44	0.22

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SAMPLE No	DEPTH	Total Sulphur %	Free Sulphate %	Sulphidic Sulphur %	TOC
MCC 001/01	0-5 CM	0.13	0.12	0.01	0.58
MCC 001/02	10-15 CM	0.90	0.41	0.49	13.04
MCC 001/03	20-25 CM	1.24	0.36	0.88	7.90
MCC 001/04	30-35 CM	1.30	0.22	1.08	3.16
MCC 001/05	40-45 CM	1.91	0.19	1.71	4.24
MCC 001/06	50-55 CM	2.33	0.29	2.04	4.77
MCC 001/07	75-80 CM	0.80	0.15	0.64	1.83
MCC 001/08	100-105 CM	0.93	0.17	0.76	1.78
MCC 001/09	125-130 CM	0.43	0.08	0.35	0.94
MCC 002/01	0-5 CM	0.63	0.27	0.36	8.23
MCC 002/02	10-15 CM	0.55	0.23	0.32	7.66
MCC 002/03	20-25 CM	2.98	0.34	2.64	7.60
MCC 002/04	30-35 CM	1.35	0.15	1.20	5.61
MCC 002/05	40-45 CM	2.23	0.21	2.02	4.34
MCC 002/06	50-55 CM	1.47	0.13	1.35	4.16
MCC 002/07	75-80 CM	0.68	0.06	0.62	0.29
MCC 002/08	100-105 CM	0.48	0.05	0.43	0.25
MCC 003/01	0-5 CM	0.18	0.03	0.15	0.98
MCC 003/02	15-20 CM	2.59	0.18	2.41	5.10
MCC 003/03	25-30 CM	1.58	0.11	1.47	1.86
MCC 003/04	30-35 CM	1.04	0.10	0.94	0.76
MCC 003/05	40-45 CM	0.99	0.04	0.95	0.64
MCC 003/06	50-55 CM	0.65	0.02	0.63	0.41
MCC 003/07	75-80 CM	0.30	0.02	0.28	0.12
MCC 003/08	100-105 CM	0.40	0.03	0.38	0.44
MCC 004/01	0-5 CM	0.14	0.05	0.09	0.81
MCC 004/02	10-15 CM	1.03	0.20	0.83	13.27
MCC 004/03	20-25 CM	0.88	0.08	0.80	5.37
MCC 004/04	30-35 CM	2.14	0.14	2.00	4.89
MCC 004/05	40-45 CM	1.43	0.13	1.30	2.71
MCC 004/06	50-55 CM	1.39	0.12	1.27	4.07
MCC 004/07	75-80 CM	0.86	0.08	0.78	0.45
MCC 005/01	0-5 CM	0.62	0.21	0.41	12.10
MCC 005/02	10-15 CM	0.65	0.17	0.48	8.50
MCC 005/03	20-25 CM	1.88	0.12	1.76	4.53
MCC 005/04	30-35 CM	2.35	0.16	2.19	10.57
MCC 005/05	40-45 CM	2.83	0.19	2.64	3.37
MCC 005/06	50-55 CM	1.42	0.11	1.31	1.70
MCC 005/07	75-80 CM	0.73	0.04	0.69	12.57
MCC 005/08	100-105 CM	0.38	0.03	0.35	0.11
MCC 006/01	0-5 CM	0.19	0.15	0.03	14.19
MCC 006/02	10-15 CM	2.19	0.12	2.06	9.57
MCC 006/03	20-25 CM	2.39	0.14	2.26	7.42
MCC 006/04	30-35 CM	3.21	0.17	3.04	9.49
MCC 006/05	40-45 CM	3.22	0.20	3.03	8.65
MCC 006/06	50-55 CM	2.68	0.16	2.51	6.46
MCC 006/07	75-80 CM	1.25	0.07	1.18	1.02
MCC 006/08	100-105 CM	0.43	0.03	0.40	0.74
MCC 007/01	0-5 CM	0.19	0.06	0.12	1.45
MCC 007/02	10-15 CM	1.04	0.09	0.96	2.18
MCC 007/03	20-25 CM	0.21	0.06	0.15	1.34
MCC 007/04	30-35 CM	2.84	0.18	2.66	5.34
MCC 007/05	40-45 CM	1.33	0.12	1.21	2.15
MCC 007/06	50-55 CM	1.21	0.07	1.15	1.08
MCC 007/07	75-80 CM	0.57	0.04	0.53	0.71
MCC 008/01	0-5 CM	1.28	0.21	1.06	2.00
MCC 008/02	10-15 CM	2.61	0.24	2.37	2.28
MCC 008/03	20-25 CM	2.21	0.14	2.08	4.99
MCC 008/04	30-35 CM	3.67	0.11	3.55	6.84
MCC 008/05	40-45 CM	2.24	0.10	2.14	9.89
MCC 008/06	50-55 CM	3.33	0.16	3.16	10.22
MCC 008/07	75-80 CM	1.46	0.04	1.42	2.85
MCC 008/08	100-105 CM	0.53	0.04	0.49	3.60
MCC 009/01	0-5 CM	1.74	0.10	1.63	7.70

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SAMPLE No	DEPTH	Total Sulphur %	Free Sulphate %	Sulphidic Sulphur %	TOC
MCC 009/02	10-15 CM	2.78	0.06	2.71	9.50
MCC 009/03	20-25 CM	2.07	0.07	2.01	5.82
MCC 009/04	30-35 CM	2.87	0.14	2.74	6.82
MCC 009/05	40-45 CM	1.65	0.04	1.60	4.06
MCC 009/06	50-55 CM	1.20	0.04	1.16	3.98
MCC 009/07	75-80 CM	0.49	0.02	0.47	2.79
MCC 009/08	100-105 CM	1.59	0.04	1.55	4.24
MCC 010/01	0-5 CM	3.78	0.14	3.63	9.23
MCC 010/02	10-15 CM	4.35	0.15	4.20	9.79
MCC 010/03	20-25 CM	4.59	0.14	4.44	7.68
MCC 010/04	30-35 CM	3.00	0.11	2.88	7.01
MCC 010/05	40-45 CM	2.48	0.06	2.41	5.53
MCC 010/06	50-55 CM	1.52	0.03	1.49	3.84
MCC 010/07	75-80 CM	0.33	0.02	0.31	2.75
MCC 011/01	0-5 CM	1.43	0.16	1.27	21.03
MCC 011/02	10-15 CM	1.68	0.11	1.57	13.02
MCC 011/03	20-25 CM	2.69	0.17	2.52	12.08
MCC 011/04	30-35 CM	1.15	0.11	1.05	4.47
MCC 011/05	40-45 CM	1.36	0.07	1.29	3.36
MCC 011/06	50-55 CM	0.93	0.04	0.89	3.29
MCC 011/07	75-80 CM	0.02	0.03	0.00	1.54
MCC 012/01	0-5 CM	0.21	0.11	0.10	13.22
MCC 012/02	10-15 CM	0.33	0.26	0.07	16.48
MCC 012/03	20-25 CM	0.64	0.22	0.43	11.77
MCC 012/04	30-35 CM	0.83	0.17	0.65	9.90
MCC 012/05	40-45 CM	0.66	0.11	0.55	8.81
MCC 012/06	50-55 CM	1.76	0.17	1.59	9.45
MCC 012/07	75-80 CM	1.37	0.12	1.25	3.80

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Total Analysis Data

SAMPLE No	DEPTH	DISTANCE m	WEIGHT g	Cu	Cd	Pb	Zn
GS 001	T1 05	30.00	1.0173	63.53	0.77	46.97	98.14
GS 002	T1 30	30.00	1.0582	37.57	0.00	28.49	81.60
GS 003	T1 05	55.00	1.0194	45.35	0.43	37.84	65.14
GS 004	T1 30	55.00	1.0039	39.69	1.11	30.55	588.91
GS 005	T1 05	100.00	1.0174	50.94	0.00	35.94	63.16
GS 006	T1 30	100.00	1.0615	34.10	0.55	27.73	285.36
GS 007	T1 05	130.00	1.0750	51.16	0.00	42.63	104.29
GS 008	T1 30	130.00	1.1008	31.24	0.48	22.33	74.54
GS 009	T1 05	175.00	1.1911	51.70	0.38	34.64	68.37
GS 010	T1 30	175.00	1.0605	34.80	0.57	25.37	235.02
GS 011	T1 05	220.00	1.0108	57.46	0.55	33.13	112.12
GS 012	T1 30	220.00	1.1659	30.58	0.00	16.05	73.85
GS 013	T1 05	285.00	1.0133	19.36	0.00	6.93	45.56
GS 014	T1 30	285.00	1.0782	20.31	0.00	6.85	52.77
GS 015	T3 05	35.00	1.0358	46.55	0.56	40.20	112.38
GS 016	T3 30	35.00	1.0229	26.22	0.00	15.08	66.12
GS 017	T3 05	90.00	1.0173	34.55	0.46	32.01	117.74
GS 018	T3 30	90.00	1.2535	22.30	0.00	16.04	67.90
GS 019	T3 05	130.00	1.0365	24.64	0.00	20.69	53.42
GS 020	T3 30	130.00	1.0200	20.98	0.00	13.04	65.41
GS 021	T3 05	190.00	1.0608	37.36	0.42	28.86	60.00
GS 022	T3 30	190.00	1.0044	20.31	0.00	16.29	69.78
GS 023	T3 05	230.00	1.0217	34.48	0.00	29.31	179.41
GS 024	T3 30	230.00	1.0058	24.95	0.00	19.91	76.70
GS 025	T3 05	270.00	1.1170	31.36	0.31	29.62	77.03
GS 026	T3 30	270.00	1.0103	23.54	0.00	17.15	108.53
GS 027	T3 05	305.00	1.1642	22.66	0.00	16.07	96.56
GS 028	T3 30	305.00	1.0162	23.36	0.00	13.11	54.18
GS 029	T3 05	365.00	1.4150	14.02	0.00	7.66	97.29
GS 030	T3 30	365.00	1.1132	21.96	0.00	5.66	36.99
GS 031	T2 05	35.00	1.0703	37.10	0.00	19.81	71.68
GS 032	T2 30	35.00	1.0084	21.20	0.00	10.21	88.75
GS 033	T2 05	70.00	1.0093	38.25	0.00	37.71	65.11
GS 034	T2 30	70.00	1.1373	28.96	0.00	13.21	57.89
GS 035	T2 05	100.00	1.0783	41.41	0.00	25.04	50.34
GS 036	T2 30	100.00	1.0347	22.99	0.00	15.46	56.25
GS 037	T2 05	155.00	1.0475	34.10	0.00	36.29	56.58
GS 038	T2 30	155.00	1.0086	24.40	0.00	19.83	36.99
GS 039	T2 05	190.00	1.2803	34.86	0.00	31.68	63.14
GS 040	T2 30	190.00	1.0200	20.54	0.00	19.93	60.84
GS 041	T2 05	215.00	1.0542	31.20	0.00	29.30	73.65
GS 042	T2 30	215.00	1.0512	17.57	0.00	15.31	55.26
GS 043	T2 05	260.00	1.3015	25.70	0.14	18.59	96.96
GS 044	T2 30	260.00	1.0086	22.56	0.58	34.07	69.05
GS 045	T4 05	25.00	1.0033	35.06	0.00	39.06	84.48
GS 046	T4 30	25.00	1.0042	20.79	0.00	15.84	58.55
GS 047	T4 05	60.00	1.0055	34.69	0.00	36.83	59.53
GS 048	T4 30	60.00	1.0433	22.41	0.00	17.95	58.22
GS 049	T4 05	105.00	1.0257	17.84	0.60	16.04	33.18
GS 050	T4 30	105.00	1.0157	11.37	0.00	22.56	83.98
GS 051	T4 05	140.00	1.0167	21.54	0.32	24.26	97.51
GS 052	T4 05	160.00	1.0644	24.19	0.41	27.73	101.44
GS 053	T4 30	160.00	1.1306	20.28	0.00	25.96	93.15
GS 054	T4 05	205.00	1.2126	10.18	0.00	13.33	66.95
GS 055	T4 30	205.00	1.4439	12.10	0.00	21.62	87.47
GS 056	T5 05	105.00	1.1352	56.08	1.02	32.39	158.21
GS 057	T5 05	215.00	1.2672	60.72	0.28	57.08	121.97
GS 058	T5 30	315.00	1.1611	20.62	0.00	16.16	98.82
GS 059	T5 05	315.00	1.0458	32.21	0.28	11.99	118.91
GS 060	T5 30	405.00	1.0182	17.93	0.00	28.58	70.44
GS 061	T5 05	405.00	1.1442	36.01	0.00	27.62	130.26
GS 062	T5 30	435.00	1.1039	29.02	0.00	28.38	113.26
GS 063	T5 05	435.00	1.1161	29.89	0.00	14.89	91.84
GS 064	T5 30	470.00	1.0267	22.95	0.29	37.18	106.25
GS 065	T5 05	470.00	1.0885	28.71	0.00	25.84	89.22
GS 066	T5 30	530.00	1.0249	15.51	0.00	34.69	69.57
GS 067	T5 05	530.00	1.0111	26.54	0.00	19.03	120.22
GS 068	T5 30	580.00	1.2402	7.61	0.00	14.94	126.33
GS 069	T5 05	580.00	1.3446	8.15	0.00	4.31	55.07

Appendix 2-20

Total Analysis Data

SAMPLE No	DEPTH	Hg	Cr	Ni	Sn	Fe %
GS 001	T1 05	0.10	3.60	11.56	110.66	2.29
GS 002	T1 30	3.60	6.94	16.26	124.57	3.59
GS 003	T1 05	0.31	5.76	21.09	199.36	1.37
GS 004	T1 30	1.20	8.05	16.94	139.04	4.37
GS 005	T1 05	0.59	5.41	22.50	121.97	1.15
GS 006	T1 30	0.60	7.96	23.20	120.53	4.11
GS 007	T1 05	0.58	8.21	21.79	104.72	2.22
GS 008	T1 30	0.62	8.68	13.56	91.89	3.33
GS 009	T1 05	0.24	5.55	16.94	127.04	1.53
GS 010	T1 30	0.54	10.06	14.23	95.38	4.48
GS 011	T1 05	0.27	8.00	16.94	115.16	3.42
GS 012	T1 30	1.81	7.57	11.56	73.82	5.01
GS 013	T1 05	0.56	3.25	6.36	27.01	1.73
GS 014	T1 30	1.35	3.40	10.24	35.41	2.65
GS 015	T3 05	2.59	4.60	21.09	172.86	2.53
GS 016	T3 30	2.57	6.10	19.70	73.19	4.78
GS 017	T3 05	2.59	6.86	14.23	137.21	2.86
GS 018	T3 30	2.79	7.63	29.69	83.72	4.93
GS 019	T3 05	3.47	5.67	14.90	116.01	1.33
GS 020	T3 30	2.57	7.20	26.06	106.62	4.46
GS 021	T3 05	2.46	6.58	18.31	109.73	1.67
GS 022	T3 30	2.41	8.42	22.50	100.71	4.10
GS 023	T3 05	2.50	6.47	16.26	102.72	1.90
GS 024	T3 30	0.81	8.40	21.79	111.92	3.82
GS 025	T3 05	1.52	8.23	19.70	111.09	2.28
GS 026	T3 30	3.46	9.46	18.31	88.91	3.46
GS 027	T3 05	2.97	4.73	12.89	70.71	2.26
GS 028	T3 30	4.25	7.59	16.90	70.01	4.16
GS 029	T3 05	0.22	2.33	11.56	37.26	1.85
GS 030	T3 30	0.76	4.28	10.90	40.81	2.04
GS 031	T2 05	0.32	5.14	19.70	141.38	1.77
GS 032	T2 30	0.20	7.29	19.70	89.07	4.26
GS 033	T2 05	0.81	6.55	16.94	157.72	1.30
GS 034	T2 30	0.51	7.43	25.34	150.42	4.51
GS 035	T2 05	2.58	8.18	16.26	222.74	3.05
GS 036	T2 30	1.29	5.68	23.91	80.52	3.79
GS 037	T2 05	0.76	5.26	16.94	159.53	2.36
GS 038	T2 30	0.21	7.65	19.00	130.69	3.09
GS 039	T2 05	0.22	5.16	19.00	146.11	1.58
GS 040	T2 30	nd	5.76	16.26	116.63	1.54
GS 041	T2 05	0.21	6.97	18.31	79.03	2.44
GS 042	T2 30	0.23	8.39	18.31	79.26	3.23
GS 043	T2 05	0.24	8.19	22.50	50.38	2.84
GS 044	T2 30	nd	8.38	9.59	65.00	4.49
GS 045	T4 05	0.79	6.96	12.89	83.04	1.88
GS 046	T4 30	0.63	5.48	16.94	82.96	3.88
GS 047	T4 05	nd	9.14	11.56	89.33	1.46
GS 048	T4 30	1.12	4.92	16.26	79.86	4.01
GS 049	T4 05	nd	9.32	8.94	98.58	1.73
GS 050	T4 30	nd	3.24	21.79	133.60	5.01
GS 051	T4 05	nd	8.68	14.90	137.29	4.39
GS 052	T4 05	0.45	6.56	18.31	98.60	3.95
GS 053	T4 30	nd	6.83	22.50	116.59	5.48
GS 054	T4 05	nd	6.67	15.58	39.47	3.42
GS 055	T4 30	0.40	2.79	24.63	45.41	3.49
GS 056	T5 05	nd	6.80	22.50	109.31	2.83
GS 057	T5 05	0.69	7.54	26.78	30.13	1.97
GS 058	T5 30	nd	7.28	31.17	20.49	6.48
GS 059	T5 05	0.33	4.21	10.90	144.69	3.55
GS 060	T5 30	0.67	4.68	6.36	44.62	3.21
GS 061	T5 05	0.05	4.17	8.94	62.18	2.00
GS 062	T5 30	0.13	5.65	14.90	74.57	2.80
GS 063	T5 05	0.15	3.28	8.94	47.24	1.59
GS 064	T5 30	nd	5.72	12.89	76.54	2.05
GS 065	T5 05	1.23	2.35	8.29	45.08	1.48
GS 066	T5 30	1.21	5.01	7.00	62.20	2.99
GS 067	T5 05	0.29	4.72	8.29	41.34	1.76
GS 068	T5 30	1.20	1.76	11.56	27.87	2.34
GS 069	T5 05	1.15	5.23	8.92	15.04	1.51

Appendix 2-21

BaCl/ NH4ClExtractable

SAMPLE No	DEPTH	DISTANCE m	Weight	Cd	Pb	Cu	Hg	Zn
GS 001	T1 05	30.00	2.06	N/A	4.41	2.75	0.01	1.50
GS 002	T1 30	30.00	2.00	N/A	4.72	1.94	nd	4.61
GS 003	T1 05	55.00	2.02	N/A	5.24	1.93	nd	0.77
GS 004	T1 30	55.00	2.10	N/A	5.41	2.07	nd	251.27
GS 005	T1 05	100.00	2.01	N/A	5.07	3.48	nd	0.85
GS 006	T1 30	100.00	2.01	N/A	4.71	1.28	nd	36.81
GS 007	T1 05	130.00	2.04	N/A	4.27	2.34	nd	1.27
GS 008	T1 30	130.00	2.01	N/A	4.53	2.60	0.01	1.52
GS 009	T1 05	175.00	2.05	N/A	4.61	1.90	nd	0.97
GS 010	T1 30	175.00	2.12	N/A	3.75	1.63	nd	37.40
GS 011	T1 05	220.00	2.07	N/A	4.02	3.31	nd	2.40
GS 012	T1 30	220.00	2.02	N/A	4.50	1.71	nd	22.09
GS 013	T1 05	285.00	2.01	N/A	2.84	1.28	nd	1.76
GS 014	T1 30	285.00	2.15	N/A	3.18	1.81	nd	7.18
GS 015	T3 05	35.00	2.02	N/A	5.60	4.13	nd	1.09
GS 016	T3 30	35.00	2.10	N/A	3.42	1.85	0.01	1.32
GS 017	T3 05	90.00	2.00	N/A	6.61	3.95	nd	1.13
GS 018	T3 30	90.00	2.04	N/A	3.90	2.35	nd	1.59
GS 019	T3 05	130.00	2.07	N/A	5.65	3.17	nd	1.03
GS 020	T3 30	130.00	2.02	N/A	3.57	1.28	nd	0.63
GS 021	T3 05	190.00	2.00	N/A	5.29	2.83	nd	1.20
GS 022	T3 30	190.00	2.03	N/A	4.10	1.48	nd	3.44
GS 023	T3 05	230.00	2.07	N/A	4.76	3.39	nd	1.07
GS 024	T3 30	230.00	2.00	N/A	4.34	2.16	nd	2.18
GS 025	T3 05	270.00	2.08	N/A	4.90	2.30	0.02	0.81
GS 026	T3 30	270.00	2.00	N/A	4.72	1.95	nd	1.51
GS 027	T3 05	305.00	2.07	N/A	4.02	2.31	nd	1.05
GS 028	T3 30	305.00	2.02	N/A	4.32	2.15	0.01	11.48
GS 029	T3 05	365.00	2.02	N/A	3.19	1.49	nd	1.51
GS 030	T3 30	365.00	2.02	N/A	3.38	1.93	nd	0.82
GS 031	T2 05	35.00	2.09	N/A	7.05	3.42	nd	2.13
GS 032	T2 30	35.00	2.01	N/A	4.34	1.94	nd	2.68
GS 033	T2 05	70.00	2.08	N/A	7.26	3.80	nd	1.57
GS 034	T2 30	70.00	2.00	N/A	4.16	2.83	nd	1.04
GS 035	T2 05	100.00	2.08	N/A	5.80	3.08	0.01	1.89
GS 036	T2 30	100.00	2.30	N/A	4.11	2.72	nd	4.30
GS 037	T2 05	155.00	2.15	N/A	5.27	1.40	nd	1.62
GS 038	T2 30	155.00	2.07	N/A	4.39	0.68	nd	1.08
GS 039	T2 05	190.00	2.15	N/A	5.09	0.99	nd	1.49
GS 040	T2 30	190.00	2.08	N/A	4.38	2.02	nd	1.71
GS 041	T2 05	215.00	2.15	N/A	4.75	1.20	nd	1.34
GS 042	T2 30	215.00	2.11	N/A	4.83	2.54	nd	1.52
GS 043	T2 05	260.00	2.04	N/A	4.83	1.12	0.01	1.74
GS 044	T2 30	260.00	2.09	N/A	4.35	2.08	nd	21.08
GS 045	T4 05	25.00	2.02	N/A	6.17	1.20	nd	1.60
GS 046	T4 30	25.00	2.01	N/A	4.88	0.77	nd	1.28
GS 047	T4 05	60.00	2.05	N/A	5.15	1.40	nd	1.56
GS 048	T4 30	60.00	2.02	N/A	5.25	0.84	nd	2.21
GS 049	T4 05	105.00	2.02	N/A	4.12	2.00	nd	1.16
GS 050	T4 30	105.00	2.07	N/A	4.40	3.25	nd	7.76
GS 051	T4 05	140.00	2.08	N/A	4.01	0.89	nd	22.29
GS 052	T4 05	160.00	2.08	N/A	3.83	1.03	0.02	14.92
GS 053	T4 30	160.00	2.18	N/A	3.82	0.98	nd	21.46
GS 054	T4 05	205.00	2.16	N/A	2.82	1.05	0.01	12.32
GS 055	T4 30	205.00	2.09	N/A	3.26	1.16	nd	9.78
GS 056	T5 05	105.00	2.02	N/A	5.62	1.57	nd	1.37
GS 057	T5 05	215.00	2.09	N/A	5.98	1.37	nd	0.88
GS 058	T5 30	315.00	2.00	N/A	4.16	1.29	nd	2.68
GS 059	T5 05	315.00	2.07	N/A	6.04	2.39	nd	2.56
GS 060	T5 30	405.00	2.11	N/A	3.94	1.29	nd	1.52
GS 061	T5 05	405.00	2.15	N/A	4.93	0.99	nd	1.46
GS 062	T5 30	435.00	2.05	N/A	5.17	0.76	nd	4.51
GS 063	T5 05	435.00	2.02	N/A	5.06	0.91	0.02	1.29
GS 064	T5 30	470.00	2.02	N/A	5.06	0.99	nd	1.43
GS 065	T5 05	470.00	2.07	N/A	4.75	1.24	nd	1.62
GS 066	T5 30	530.00	2.19	N/A	3.97	0.64	nd	2.78
GS 067	T5 05	530.00	2.20	N/A	4.13	1.24	nd	1.30
GS 068	T5 30	580.00	2.01	N/A	3.40	0.63	nd	3.66
GS 069	T5 05	580.00	2.05	N/A	2.97	1.61	nd	1.50

Appendix 2-22

BaCl/ NH4Cl Extractable

SAMPLE No	DEPTH	Cr	Ni	Fe %
GS 001	T1 05	0.06	2.67	0.0004
GS 002	T1 30	0.06	2.84	0.0005
GS 003	T1 05	0.15	3.01	0.0008
GS 004	T1 30	0.06	4.60	0.0027
GS 005	T1 05	0.06	2.92	0.0004
GS 006	T1 30	0.02	2.83	0.0019
GS 007	T1 05	0.11	2.32	0.0005
GS 008	T1 30	0.06	2.64	0.0004
GS 009	T1 05	0.06	2.77	0.0013
GS 010	T1 30	0.10	2.77	0.0004
GS 011	T1 05	0.10	1.64	0.0006
GS 012	T1 30	0.11	6.41	0.0161
GS 013	T1 05	0.02	1.69	0.0005
GS 014	T1 30	0.02	4.77	0.0115
GS 015	T3 05	0.20	4.27	0.0005
GS 016	T3 30	0.06	2.16	0.0004
GS 017	T3 05	0.16	4.41	0.0005
GS 018	T3 30	0.11	2.04	0.0010
GS 019	T3 05	0.19	3.59	0.0005
GS 020	T3 30	0.06	1.97	0.0003
GS 021	T3 05	0.16	3.52	0.0008
GS 022	T3 30	0.02	2.99	0.0008
GS 023	T3 05	0.20	3.03	0.0009
GS 024	T3 30	0.06	2.84	0.0004
GS 025	T3 05	0.10	2.64	0.0005
GS 026	T3 30	0.11	2.65	0.0048
GS 027	T3 05	0.06	2.10	0.0003
GS 028	T3 30	0.06	5.69	0.0167
GS 029	T3 05	0.02	1.96	0.0003
GS 030	T3 30	0.02	1.78	0.0002
GS 031	T2 05	0.24	6.18	0.0098
GS 032	T2 30	0.15	2.26	0.0003
GS 033	T2 05	0.24	4.43	0.0005
GS 034	T2 30	0.06	2.55	0.0005
GS 035	T2 05	0.15	3.86	0.0006
GS 036	T2 30	0.09	3.06	0.0024
GS 037	T2 05	0.14	3.18	0.0007
GS 038	T2 30	0.11	2.38	0.0003
GS 039	T2 05	0.14	1.58	0.0008
GS 040	T2 30	0.06	2.46	0.0003
GS 041	T2 05	0.14	2.92	0.0003
GS 042	T2 30	0.06	2.42	0.0004
GS 043	T2 05	0.02	2.32	0.0008
GS 044	T2 30	0.06	5.01	0.0142
GS 045	T4 05	0.15	3.29	0.0004
GS 046	T4 30	0.11	2.73	0.0003
GS 047	T4 05	0.11	2.58	0.0004
GS 048	T4 30	0.15	2.44	0.0002
GS 049	T4 05	0.06	2.15	0.0002
GS 050	T4 30	0.11	4.66	0.0104
GS 051	T4 05	0.06	3.40	0.0018
GS 052	T4 05	0.02	3.11	0.0031
GS 053	T4 30	0.01	4.97	0.0092
GS 054	T4 05	0.06	4.08	0.0066
GS 055	T4 30	0.02	4.80	0.0104
GS 056	T5 05	0.20	4.08	0.0004
GS 057	T5 05	0.24	4.33	0.0003
GS 058	T5 30	0.11	3.03	0.0004
GS 059	T5 05	0.20	4.66	0.0004
GS 060	T5 30	0.06	2.42	0.0007
GS 061	T5 05	0.10	3.01	0.0004
GS 062	T5 30	0.24	3.25	0.0004
GS 063	T5 05	0.15	2.63	0.0004
GS 064	T5 30	0.15	2.92	0.0004
GS 065	T5 05	0.11	2.47	0.0003
GS 066	T5 30	0.10	2.24	0.0005
GS 067	T5 05	0.10	2.24	0.0005
GS 068	T5 30	0.06	2.64	0.0008
GS 069	T5 05	0.02	1.39	0.0001

Appendix 2-23

Acetate Extrctable

SAMPLE No	DISTANCE m	Cd	Pb	Cu	Hg	Zn	Cr	Ni	Fe
GS 001	30.00	N/A	4.66	5.48	1.08	34.55	0.36	3.86	0.0431
GS 002	30.00	N/A	1.91	2.18	0.93	5.12	0.21	2.63	0.0041
GS 003	55.00	N/A	2.98	2.36	nd	7.44	0.21	2.46	0.0032
GS 004	55.00	N/A	2.74	2.35	nd	48.92	0.23	2.23	0.0118
GS 005	100.00	N/A	4.16	2.10	nd	6.15	0.30	2.47	0.0020
GS 006	100.00	N/A	3.50	2.07	nd	41.60	0.27	3.14	0.0070
GS 007	130.00	N/A	5.53	3.05	nd	84.36	0.21	2.51	0.0028
GS 008	130.00	N/A	1.82	1.03	1.13	5.11	0.24	2.62	0.0032
GS 009	175.00	N/A	3.83	2.17	nd	7.22	0.27	2.14	0.0029
GS 010	175.00	N/A	3.22	1.51	nd	29.31	0.20	2.62	0.0032
GS 011	220.00	N/A	3.23	4.48	1.26	16.19	0.18	2.47	0.0048
GS 012	220.00	N/A	1.52	2.97	1.67	2.96	0.18	2.11	0.0256
GS 013	285.00	N/A	2.14	3.05	1.28	3.27	0.21	2.11	0.0111
GS 014	285.00	N/A	1.25	2.77	1.07	1.94	0.23	1.98	0.0146
GS 015	35.00	N/A	4.40	3.31	1.09	32.41	0.49	3.93	0.0304
GS 016	35.00	N/A	0.90	3.64	1.23	2.54	0.23	2.15	0.0066
GS 017	90.00	N/A	4.01	3.04	1.12	37.67	0.40	3.22	0.0281
GS 018	90.00	N/A	1.06	2.38	1.06	2.94	0.30	2.58	0.0031
GS 019	130.00	N/A	0.94	2.75	0.80	4.99	0.33	2.47	0.0101
GS 020	130.00	N/A	0.65	2.58	1.08	2.20	0.34	2.32	0.0094
GS 021	190.00	N/A	1.58	3.18	1.03	4.77	0.24	2.34	0.0038
GS 022	190.00	N/A	1.64	2.66	1.47	2.72	0.18	1.95	0.0074
GS 023	230.00	N/A	1.99	3.09	0.80	5.86	0.27	2.20	0.0032
GS 024	230.00	N/A	2.02	7.10	1.29	7.29	0.24	2.99	0.0025
GS 025	270.00	N/A	3.07	2.65	0.97	5.06	0.29	2.88	0.0035
GS 026	270.00	N/A	1.20	2.45	1.39	2.67	0.21	2.05	0.0018
GS 027	305.00	N/A	1.87	2.27	1.24	8.98	0.21	2.33	0.0070
GS 028	305.00	N/A	0.64	1.95	nd	1.77	0.15	2.25	0.0231
GS 029	365.00	N/A	1.36	2.36	nd	4.15	0.21	2.24	0.0104
GS 030	365.00	N/A	1.09	2.73	nd	2.32	0.24	2.97	0.0088
GS 031	35.00	N/A	3.25	2.36	1.01	14.43	0.35	3.08	0.0078
GS 032	35.00	N/A	0.61	0.78	0.69	4.96	0.18	2.26	0.0035
GS 033	70.00	N/A	2.57	0.71	nd	10.13	0.14	2.25	0.0067
GS 034	70.00	N/A	0.87	0.81	0.70	2.99	0.15	2.19	0.0033
GS 035	100.00	N/A	3.51	1.34	0.77	4.04	0.23	2.74	0.0010
GS 036	100.00	N/A	2.63	0.88	0.89	1.95	0.19	2.67	0.0039
GS 037	155.00	N/A	3.16	1.50	1.03	3.87	0.27	2.72	0.0018
GS 038	155.00	N/A	2.69	0.82	0.79	1.56	0.28	2.62	0.0010
GS 039	190.00	N/A	4.09	0.87	0.71	3.36	0.30	2.99	0.0011
GS 040	190.00	N/A	2.68	0.98	0.66	1.51	0.28	2.33	0.0005
GS 041	215.00	N/A	3.87	1.11	0.65	4.62	0.30	2.86	0.0002
GS 042	215.00	N/A	3.10	0.68	0.91	1.57	0.28	2.49	0.0007
GS 043	260.00	N/A	3.71	1.21	0.94	6.25	0.32	3.16	0.0035
GS 044	260.00	N/A	2.42	1.26	1.37	2.08	0.31	2.60	0.0136
GS 045	25.00	N/A	3.49	1.47	0.92	5.36	0.35	2.68	0.0013
GS 046	25.00	N/A	3.01	1.10	nd	1.74	0.29	2.54	0.0008
GS 047	60.00	N/A	4.54	1.61	nd	7.35	0.28	2.78	0.0014
GS 048	60.00	N/A	3.62	0.93	nd	2.35	0.32	2.54	0.0017
GS 049	105.00	N/A	4.23	1.05	0.10	6.41	0.23	2.60	0.0024
GS 050	105.00	N/A	2.45	1.73	0.87	4.32	0.22	2.41	0.0071
GS 051	140.00	N/A	3.52	1.60	0.84	3.87	0.22	2.75	0.0060
GS 052	160.00	N/A	3.64	1.14	0.11	6.42	0.22	3.10	0.0046
GS 053	160.00	N/A	2.66	1.20	4.32	2.60	0.27	3.02	0.0118
GS 054	205.00	N/A	2.57	1.02	0.89	1.64	0.21	2.64	0.0046
GS 055	205.00	N/A	2.53	0.81	3.35	1.23	0.22	2.87	0.0062
GS 056	105.00	N/A	6.40	1.81	4.51	26.52	0.26	3.94	0.0160
GS 057	215.00	N/A	4.23	1.18	nd	4.93	0.31	3.38	0.0009
GS 058	315.00	N/A	3.28	0.93	0.11	2.30	0.26	3.07	0.0034
GS 059	315.00	N/A	6.37	1.77	4.02	24.59	0.50	4.96	0.0171
GS 060	405.00	N/A	3.34	0.92	0.33	4.70	0.28	3.33	0.0019
GS 061	405.00	N/A	4.58	1.42	4.49	16.47	0.30	3.28	0.0017
GS 062	435.00	N/A	3.70	0.82	nd	8.41	0.25	3.15	0.0023
GS 063	435.00	N/A	4.37	1.37	nd	5.62	0.35	3.27	0.0012
GS 064	470.00	N/A	3.62	0.87	nd	3.10	0.38	2.90	0.0012
GS 065	470.00	N/A	4.88	1.38	nd	5.16	0.41	3.41	0.0009
GS 066	530.00	N/A	3.22	1.07	nd	3.05	0.21	2.74	0.0013
GS 067	530.00	N/A	4.36	1.15	nd	5.63	0.27	3.00	0.0013
GS 068	580.00	N/A	2.89	0.71	0.10	1.34	0.26	2.40	0.0035
GS 069	580.00	N/A	3.19	1.19	0.09	4.89	0.25	2.42	0.0027

Appendix 2-24

Dithionite Extractable

SAMPLE No	DISTANCE m	Cd	Pb	Cu	Hg	Zn	Cr	Ni	Fe
GS 001	30.00	N/A	9.57	7.07	1.22	21.98	0.81	5.10	0.58
GS 002	30.00	N/A	7.67	2.50	0.33	14.67	0.76	5.10	0.33
GS 003	55.00	N/A	6.68	11.13	0.56	15.00	0.63	4.78	0.08
GS 004	55.00	N/A	6.95	3.22	0.66	50.23	0.79	4.94	0.28
GS 005	100.00	N/A	6.30	6.59	0.46	18.88	0.73	5.28	0.10
GS 006	100.00	N/A	6.72	1.94	nd	40.80	0.67	7.84	0.24
GS 007	130.00	N/A	6.35	5.61	0.29	18.21	0.60	4.87	0.19
GS 008	130.00	N/A	6.06	1.81	nd	13.15	0.64	5.38	0.17
GS 009	175.00	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GS 010	175.00	N/A	6.35	1.87	nd	39.38	0.66	5.50	0.14
GS 011	220.00	N/A	6.12	2.92	nd	4.41	0.65	4.44	0.40
GS 012	220.00	N/A	6.29	1.38	nd	3.72	0.67	4.08	0.32
GS 013	285.00	N/A	6.84	2.71	nd	5.55	0.67	4.37	0.15
GS 014	285.00	N/A	5.66	1.85	nd	1.92	0.54	5.84	0.11
GS 015	35.00	N/A	8.13	10.57	0.36	24.44	0.70	5.05	0.53
GS 016	35.00	N/A	6.66	3.38	0.18	4.57	0.61	4.78	0.44
GS 017	90.00	N/A	8.34	16.95	2.15	90.25	0.70	5.39	0.52
GS 018	90.00	N/A	6.62	1.82	0.17	7.65	0.63	4.59	0.25
GS 019	130.00	N/A	6.89	7.58	0.09	11.14	0.59	4.86	0.13
GS 020	130.00	N/A	7.49	3.66	nd	28.64	0.64	6.15	0.23
GS 021	190.00	N/A	6.87	4.53	nd	10.67	0.58	4.32	0.14
GS 022	190.00	N/A	7.43	2.04	nd	7.01	0.75	4.88	0.24
GS 023	230.00	N/A	7.05	6.56	13.65	67.13	0.65	4.53	0.15
GS 024	230.00	N/A	7.53	2.20	nd	12.56	0.67	8.16	0.14
GS 025	270.00	N/A	7.38	4.31	0.07	12.76	0.71	4.43	0.13
GS 026	270.00	N/A	6.07	1.98	0.00	7.20	0.70	5.17	0.13
GS 027	305.00	N/A	6.90	2.84	0.16	9.31	0.71	4.38	0.14
GS 028	305.00	N/A	6.69	1.80	0.46	2.21	0.70	3.88	0.23
GS 029	365.00	N/A	7.33	2.82	0.28	9.75	0.85	5.46	0.23
GS 030	365.00	N/A	6.02	1.92	nd	3.94	0.57	4.40	0.14
GS 031	35.00	N/A	6.45	5.51	0.31	18.01	0.76	4.25	0.36
GS 032	35.00	N/A	6.45	1.55	nd	5.04	0.73	5.14	0.33
GS 033	70.00	N/A	6.35	7.27	nd	16.17	0.68	4.75	0.24
GS 034	70.00	N/A	6.20	2.33	nd	4.72	0.86	5.80	0.27
GS 035	100.00	N/A	5.29	5.74	nd	12.75	0.62	4.54	0.12
GS 036	100.00	N/A	4.68	1.21	nd	3.76	0.58	3.74	0.21
GS 037	155.00	N/A	5.23	5.25	nd	10.00	0.37	3.93	0.27
GS 038	155.00	N/A	5.68	1.94	nd	6.09	0.36	5.13	0.16
GS 039	190.00	N/A	5.00	4.59	nd	12.09	0.40	4.20	0.17
GS 040	190.00	N/A	5.07	2.78	nd	6.15	0.42	4.84	0.12
GS 041	215.00	N/A	5.47	4.78	0.06	13.53	0.34	4.41	0.24
GS 042	215.00	N/A	5.09	2.11	nd	7.13	0.44	4.48	0.09
GS 043	260.00	N/A	5.89	2.97	0.99	14.69	0.39	5.07	0.09
GS 044	260.00	N/A	6.95	7.21	nd	21.08	0.42	5.16	0.13
GS 045	25.00	N/A	6.06	6.38	nd	23.34	0.40	5.04	0.10
GS 046	25.00	N/A	5.47	2.27	nd	7.49	0.40	5.27	0.10
GS 047	60.00	N/A	8.40	12.99	0.10	24.54	0.46	5.03	0.38
GS 048	60.00	N/A	6.07	2.73	0.00	9.57	0.50	4.69	0.19
GS 049	105.00	N/A	5.68	2.44	nd	7.70	0.36	3.69	0.07
GS 050	105.00	N/A	5.45	2.98	nd	5.61	0.42	3.82	0.18
GS 051	140.00	N/A	6.26	2.38	nd	8.16	0.42	4.64	0.19
GS 052	160.00	N/A	5.78	3.95	nd	8.47	0.48	4.63	0.10
GS 053	160.00	N/A	5.73	1.53	nd	4.11	0.56	4.20	0.28
GS 054	205.00	N/A	5.21	1.89	nd	3.70	0.28	2.97	0.06
GS 055	205.00	N/A	5.50	1.51	nd	4.13	0.32	3.57	0.14
GS 056	105.00	N/A	6.32	1.99	nd	4.45	0.53	3.86	0.19
GS 057	215.00	N/A	6.35	6.14	nd	10.90	0.39	4.10	0.12
GS 058	315.00	N/A	6.24	3.12	0.09	11.10	0.47	4.42	0.17
GS 059	315.00	N/A	9.34	6.51	nd	23.57	0.52	4.81	0.45
GS 060	405.00	N/A	5.68	2.38	0.13	9.78	0.41	4.85	0.17
GS 061	405.00	N/A	5.35	4.13	0.10	31.50	0.41	3.83	0.22
GS 062	435.00	N/A	6.35	3.33	0.25	18.69	0.56	5.24	0.13
GS 063	435.00	N/A	5.46	4.67	0.14	13.34	0.33	3.70	0.19
GS 064	470.00	N/A	5.71	1.99	nd	13.61	0.33	4.31	0.07
GS 065	470.00	N/A	5.44	4.29	0.31	13.87	0.39	3.91	0.15
GS 066	530.00	N/A	5.36	1.66	nd	8.04	0.43	4.04	0.14
GS 067	530.00	N/A	6.03	4.08	0.14	12.42	0.49	3.68	0.17
GS 068	580.00	N/A	5.48	3.01	nd	4.63	0.40	3.57	0.12
GS 069	580.00	N/A	5.25	2.22	nd	6.70	0.36	3.06	0.12

Appendix 2-25

Aquaregia Extractable

SAMPLE No	DISTANCE m	Cd	Pb	Cu	Hg	Zn	Cr	Ni	Fe
GS 001	30.00	N/A	10.79	23.77	1.72	27.64	1.53	10.47	0.99
GS 002	30.00	N/A	8.73	17.68	0.95	44.61	2.45	20.63	2.24
GS 003	55.00	N/A	22.21	29.74	4.10	40.72	1.66	13.95	0.93
GS 004	55.00	N/A	16.82	23.14	0.88	80.48	2.43	20.43	3.21
GS 005	100.00	N/A	24.39	25.29	0.20	43.90	1.29	15.59	0.91
GS 006	100.00	N/A	23.33	13.76	0.21	97.56	2.84	23.59	2.88
GS 007	130.00	N/A	29.29	29.16	0.31	57.10	1.55	17.05	1.18
GS 008	130.00	N/A	14.29	15.87	0.28	48.67	2.54	16.34	2.20
GS 009	175.00	N/A	22.97	34.43	0.30	36.61	1.26	13.27	0.79
GS 010	175.00	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GS 011	220.00	N/A	14.35	11.57	nd	49.17	2.56	20.34	3.08
GS 012	220.00	N/A	10.24	13.33	nd	39.74	1.52	12.67	2.95
GS 013	285.00	N/A	6.25	6.98	nd	24.16	1.11	9.42	1.00
GS 014	285.00	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GS 015	35.00	N/A	23.85	24.87	0.24	83.09	1.37	14.01	0.98
GS 016	35.00	N/A	14.26	10.90	0.78	52.26	2.76	22.60	3.85
GS 017	90.00	N/A	21.81	22.05	0.68	47.34	1.53	12.94	1.38
GS 018	90.00	N/A	14.20	13.89	0.33	42.48	2.06	18.85	2.31
GS 019	130.00	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GS 020	130.00	N/A	25.96	32.73	0.35	60.35	2.09	18.85	2.06
GS 021	190.00	N/A	17.75	20.39	0.33	49.64	1.43	12.58	0.99
GS 022	190.00	N/A	16.12	13.56	0.17	47.12	2.31	20.13	2.80
GS 023	230.00	N/A	18.14	23.57	0.12	42.48	1.85	16.83	1.19
GS 024	230.00	N/A	17.45	15.76	0.10	45.88	2.54	19.27	2.26
GS 025	270.00	N/A	20.57	18.77	0.06	60.26	1.28	12.54	0.97
GS 026	270.00	N/A	13.10	17.16	0.30	50.69	2.82	20.85	2.35
GS 027	305.00	N/A	14.63	17.34	0.34	39.91	1.58	11.81	1.42
GS 028	305.00	N/A	8.94	15.33	nd	33.03	1.72	12.31	2.74
GS 029	365.00	N/A	7.88	8.27	nd	29.88	1.10	7.87	1.08
GS 030	365.00	N/A	7.50	6.81	nd	28.52	1.54	11.03	1.47
GS 031	35.00	N/A	15.40	16.47	0.51	37.20	1.40	12.92	1.01
GS 032	35.00	N/A	11.60	12.63	0.49	50.81	2.54	17.92	3.20
GS 033	70.00	N/A	16.52	18.66	0.29	32.07	1.19	10.61	0.96
GS 034	70.00	N/A	12.56	26.93	0.45	55.64	2.36	13.87	2.59
GS 035	100.00	N/A	14.41	28.67	1.45	31.21	1.40	12.48	0.71
GS 036	100.00	N/A	10.35	12.80	0.78	43.16	2.33	17.98	2.18
GS 037	155.00	N/A	18.31	19.75	0.68	36.14	1.24	13.22	1.13
GS 038	155.00	N/A	12.81	11.70	0.48	41.64	1.59	14.46	1.59
GS 039	190.00	N/A	19.59	18.54	0.34	39.98	1.03	16.62	0.99
GS 040	190.00	N/A	15.78	15.63	0.75	38.05	1.84	16.08	1.61
GS 041	215.00	N/A	20.84	22.36	0.09	55.74	1.44	17.12	1.21
GS 042	215.00	N/A	14.71	11.26	0.82	44.39	1.93	16.58	1.94
GS 043	260.00	N/A	17.43	17.15	1.02	41.94	2.05	16.20	1.72
GS 044	260.00	N/A	11.15	15.24	0.11	41.07	1.49	15.12	2.07
GS 045	25.00	N/A	24.97	25.66	1.77	45.75	1.23	14.09	0.82
GS 046	25.00	N/A	13.56	13.83	nd	38.55	1.76	14.14	1.64
GS 047	60.00	N/A	24.71	21.78	0.05	42.39	1.08	14.12	0.81
GS 048	60.00	N/A	14.75	12.95	1.32	51.16	1.94	16.27	2.03
GS 049	105.00	N/A	10.83	9.21	0.11	24.02	1.14	7.29	0.93
GS 050	105.00	N/A	9.45	18.82	0.32	42.48	2.15	18.81	2.56
GS 051	140.00	N/A	17.91	19.61	nd	47.39	1.41	16.70	1.01
GS 052	160.00	N/A	9.40	14.60	0.57	38.11	1.75	15.35	1.89
GS 053	160.00	N/A	10.78	10.60	0.15	42.79	1.58	17.10	2.47
GS 054	205.00	N/A	7.93	9.33	nd	28.15	1.39	12.43	1.48
GS 055	205.00	N/A	13.95	10.64	nd	41.04	2.13	16.84	2.42
GS 056	105.00	N/A	27.03	20.05	6.31	42.72	1.45	13.16	1.03
GS 057	215.00	N/A	15.84	13.76	nd	34.39	0.98	9.86	0.65
GS 058	315.00	N/A	15.54	15.78	6.11	43.26	1.51	14.23	1.82
GS 059	315.00	N/A	15.33	15.90	0.15	39.57	1.08	10.85	0.99
GS 060	405.00	N/A	14.97	8.68	nd	43.27	1.72	13.55	3.97
GS 061	405.00	N/A	20.69	20.10	nd	46.56	1.48	12.43	1.28
GS 062	435.00	N/A	16.14	12.16	nd	54.50	1.43	12.71	1.36
GS 063	435.00	N/A	18.29	19.46	0.43	44.18	1.19	16.17	0.89
GS 064	470.00	N/A	14.61	10.38	nd	65.89	1.76	13.94	1.40
GS 065	470.00	N/A	13.99	20.15	1.24	47.23	2.06	19.73	1.82
GS 066	530.00	N/A	11.59	13.06	0.27	47.42	1.87	14.47	2.06
GS 067	530.00	N/A	20.64	17.18	0.27	55.98	1.41	13.70	1.28
GS 068	580.00	N/A	6.45	7.98	nd	33.13	1.63	12.59	1.60
GS 069	580.00	N/A	5.05	7.54	nd	26.18	1.00	7.04	0.97

Appendix 2-26

Total Extractable

SAMPLE No	DISTANCE m	Cd	Pb	Cu	Hg	Zn	Cr	Ni	Fe %
GS 001	30.00	N/A	29.42	39.08	4.03	85.67	2.75	22.09	1.61
GS 002	30.00	N/A	23.03	24.30	2.21	69.01	3.49	31.19	2.57
GS 003	55.00	N/A	37.11	45.17	4.66	63.93	2.66	24.20	1.01
GS 004	55.00	N/A	31.91	30.79	1.54	430.90	3.52	32.20	3.50
GS 005	100.00	N/A	39.91	37.46	0.66	69.77	2.38	26.26	1.02
GS 006	100.00	N/A	38.26	19.05	0.21	216.77	3.80	37.40	3.13
GS 007	130.00	N/A	45.44	40.16	0.60	160.94	2.46	26.75	1.37
GS 008	130.00	N/A	26.69	21.31	1.42	68.45	3.49	26.98	2.37
GS 009	175.00	N/A	31.41	38.50	0.30	44.80	1.59	18.18	0.79
GS 010	175.00	N/A	13.32	5.00	0.00	106.09	0.97	10.89	0.15
GS 011	220.00	N/A	27.71	22.28	1.26	72.16	3.48	28.89	3.48
GS 012	220.00	N/A	22.55	19.39	1.67	68.51	2.47	25.27	3.32
GS 013	285.00	N/A	18.07	14.01	1.28	34.74	2.00	17.59	1.16
GS 014	285.00	N/A	10.09	6.43	1.07	11.03	0.78	12.59	0.13
GS 015	35.00	N/A	41.98	42.88	1.69	141.02	2.76	27.25	1.54
GS 016	35.00	N/A	25.25	19.77	2.20	60.69	3.66	31.69	4.29
GS 017	90.00	N/A	40.77	45.99	3.95	176.39	2.78	25.96	1.94
GS 018	90.00	N/A	25.77	20.45	1.56	54.65	3.10	28.06	2.56
GS 019	130.00	N/A	13.03	13.49	0.89	17.18	1.11	10.92	0.14
GS 020	130.00	N/A	37.66	40.25	1.44	91.82	3.12	29.29	2.30
GS 021	190.00	N/A	31.50	30.93	1.35	66.28	2.41	22.77	1.13
GS 022	190.00	N/A	29.29	19.74	1.64	60.29	3.26	29.95	3.05
GS 023	230.00	N/A	31.95	36.62	14.58	116.54	2.96	26.59	1.34
GS 024	230.00	N/A	31.34	27.22	1.39	67.91	3.52	33.26	2.40
GS 025	270.00	N/A	35.93	28.03	1.13	78.90	2.38	22.49	1.10
GS 026	270.00	N/A	25.10	23.54	1.69	62.07	3.85	30.72	2.48
GS 027	305.00	N/A	27.43	24.76	1.74	59.26	2.56	20.62	1.57
GS 028	305.00	N/A	20.59	21.24	0.47	48.49	2.62	24.13	3.01
GS 029	365.00	N/A	19.76	14.93	0.28	45.28	2.18	17.53	1.32
GS 030	365.00	N/A	18.00	13.39	nd	35.60	2.37	20.19	1.62
GS 031	35.00	N/A	32.14	27.77	1.83	71.77	2.75	26.43	1.39
GS 032	35.00	N/A	23.00	16.90	1.18	63.49	3.61	27.59	3.53
GS 033	70.00	N/A	32.70	30.44	0.29	59.93	2.25	22.04	1.20
GS 034	70.00	N/A	23.78	32.90	1.15	64.38	3.43	24.40	2.87
GS 035	100.00	N/A	29.01	38.83	2.22	49.89	2.40	23.62	0.84
GS 036	100.00	N/A	21.77	17.62	1.67	53.17	3.20	27.45	2.39
GS 037	155.00	N/A	31.97	27.89	1.71	51.62	2.02	23.05	1.40
GS 038	155.00	N/A	25.57	15.13	1.28	50.37	2.33	24.58	1.75
GS 039	190.00	N/A	33.78	24.99	1.05	56.92	1.88	25.39	1.16
GS 040	190.00	N/A	27.90	21.42	1.41	47.41	2.60	25.71	1.73
GS 041	215.00	N/A	34.95	29.45	0.79	75.23	2.23	27.31	1.44
GS 042	215.00	N/A	27.73	16.60	1.73	54.62	2.71	25.96	2.02
GS 043	260.00	N/A	31.86	22.46	2.97	64.62	2.78	26.76	1.82
GS 044	260.00	N/A	24.88	25.79	1.48	85.32	2.28	27.88	2.23
GS 045	25.00	N/A	40.70	34.71	2.69	76.05	2.13	25.10	0.93
GS 046	25.00	N/A	26.92	17.96	nd	49.07	2.56	24.69	1.75
GS 047	60.00	N/A	42.80	37.78	0.15	75.84	1.93	24.51	1.19
GS 048	60.00	N/A	29.69	17.44	1.32	65.30	2.91	25.94	2.22
GS 049	105.00	N/A	24.86	14.69	0.21	39.29	1.79	15.73	1.00
GS 050	105.00	N/A	21.74	26.78	1.19	60.17	2.90	29.71	2.76
GS 051	140.00	N/A	31.70	24.47	0.84	81.71	2.11	27.49	1.21
GS 052	160.00	N/A	22.64	20.72	0.70	67.93	2.47	26.20	1.99
GS 053	160.00	N/A	22.98	14.32	4.47	70.96	2.42	29.29	2.78
GS 054	205.00	N/A	18.52	13.30	0.90	45.80	1.94	22.13	1.55
GS 055	205.00	N/A	25.25	14.13	3.35	56.18	2.68	28.07	2.58
GS 056	105.00	N/A	45.37	25.41	10.83	75.06	2.44	25.04	1.24
GS 057	215.00	N/A	32.39	22.45	nd	51.10	1.92	21.66	0.77
GS 058	315.00	N/A	29.22	21.12	6.32	59.34	2.34	24.75	2.00
GS 059	315.00	N/A	37.07	26.56	4.17	90.29	2.29	25.28	1.46
GS 060	405.00	N/A	27.92	13.26	0.47	59.27	2.47	24.14	4.14
GS 061	405.00	N/A	35.55	26.64	4.59	95.98	2.29	22.54	1.50
GS 062	435.00	N/A	31.36	17.06	0.25	86.10	2.49	24.36	1.50
GS 063	435.00	N/A	33.17	26.42	0.59	64.44	2.03	25.77	1.08
GS 064	470.00	N/A	29.01	14.22	nd	84.04	2.63	24.07	1.47
GS 065	470.00	N/A	29.06	27.06	1.56	67.88	2.96	29.51	1.98
GS 066	530.00	N/A	24.15	16.42	0.27	61.29	2.60	23.50	2.20
GS 067	530.00	N/A	35.16	23.64	0.41	75.33	2.27	22.62	1.45
GS 068	580.00	N/A	18.21	12.33	0.10	42.76	2.35	21.20	1.73
GS 069	580.00	N/A	16.45	12.56	0.09	39.27	1.63	13.91	1.09

Appendix 2-27

SAMPLE No	DEPTH	Total Sulphur %	Free Sulphate %	Sulphidic Sulphur %	TOC
GS 001	T1 05	0.51	0.15	0.35	5.96
GS 002	T1 30	1.75	0.45	1.30	6.31
GS 003	T1 05	0.81	0.46	0.35	14.42
GS 004	T1 30	2.89	0.60	2.29	9.23
GS 005	T1 05	0.35	0.09	0.26	18.69
GS 006	T1 30	1.97	0.52	1.45	8.37
GS 007	T1 05	0.39	0.08	0.31	14.85
GS 008	T1 30	2.00	0.43	1.57	7.23
GS 009	T1 05	0.97	0.22	0.75	18.69
GS 010	T1 30	2.64	0.36	2.27	4.77
GS 011	T1 05	1.73	0.10	1.62	16.53
GS 012	T1 30	2.90	0.52	2.38	7.23
GS 013	T1 05	0.16	0.11	0.05	0.30
GS 014	T1 30	0.77	0.24	0.53	0.24
GS 015	T3 05	0.84	0.45	0.39	9.76
GS 016	T3 30	0.41	0.24	0.17	0.80
GS 017	T3 05	0.87	0.41	0.46	11.82
GS 018	T3 30	1.00	0.30	0.70	2.49
GS 019	T3 05	0.75	0.46	0.29	11.26
GS 020	T3 30	0.39	0.21	0.18	0.87
GS 021	T3 05	0.44	0.28	0.15	12.06
GS 022	T3 30	1.76	0.46	1.30	6.05
GS 023	T3 05	0.27	0.08	0.19	14.91
GS 024	T3 30	2.15	0.37	1.77	8.62
GS 025	T3 05	0.26	0.08	0.18	14.18
GS 026	T3 30	1.44	0.38	1.07	8.84
GS 027	T3 05	0.74	0.10	0.64	7.75
GS 028	T3 30	2.26	0.43	1.84	5.66
GS 029	T3 05	0.24	0.10	0.14	1.23
GS 030	T3 30	0.24	0.09	0.15	2.68
GS 031	T2 05	0.18	0.05	0.13	6.75
GS 032	T2 30	1.12	0.35	0.76	2.52
GS 033	T2 05	1.00	0.80	0.20	11.86
GS 034	T2 30	1.15	0.37	0.78	2.82
GS 035	T2 05	0.71	0.41	0.30	14.44
GS 036	T2 30	1.02	0.40	0.61	0.46
GS 037	T2 05	0.41	0.32	0.08	14.47
GS 038	T2 30	1.40	0.40	1.00	6.83
GS 039	T2 05	0.35	0.15	0.20	17.77
GS 040	T2 30	1.29	0.34	0.94	6.91
GS 041	T2 05	0.36	0.15	0.22	15.45
GS 042	T2 30	1.70	0.39	1.31	8.81
GS 043	T2 05	1.30	0.17	1.13	10.57
GS 044	T2 30	2.00	0.38	1.62	8.54
GS 045	T4 05	0.43	0.40	0.03	13.07
GS 046	T4 30	1.74	0.43	1.31	7.72
GS 047	T4 05	0.20	0.18	0.02	10.94
GS 048	T4 30	2.37	0.76	1.62	9.15
GS 049	T4 05	0.50	0.16	0.33	7.31
GS 050	T4 30	2.42	0.79	1.63	8.33
GS 051	T4 05	2.10	0.36	1.74	9.65
GS 052	T4 05	1.61	0.31	1.30	7.80
GS 053	T4 30	2.47	0.35	2.12	7.39
GS 054	T4 05	0.69	0.20	0.50	1.66
GS 055	T4 30	1.26	0.31	0.95	2.41
GS 056	T5 05	0.72	0.36	0.36	9.40
GS 057	T5 05	0.79	0.48	0.31	13.68
GS 058	T5 30	4.02	0.48	3.54	2.77
GS 059	T5 05	0.85	0.34	0.51	12.06
GS 060	T5 30	0.78	0.30	0.48	4.42
GS 061	T5 05	1.22	0.33	0.88	19.43
GS 062	T5 30	1.24	0.54	0.70	10.44
GS 063	T5 05	0.36	0.20	0.16	20.28
GS 064	T5 30	1.01	0.42	0.59	10.90
GS 065	T5 05	0.22	0.11	0.11	18.45
GS 066	T5 30	1.96	0.32	1.64	8.93
GS 067	T5 05	0.21	0.08	0.14	14.64
GS 068	T5 30	3.67	0.15	3.52	1.33
GS 069	T5 05	0.35	0.08	0.27	0.87

Plant Available metals

SAMPLE No	DEPTH	DISTANCE m	WEIGHT	Cd	Pb	Cu	Zn
GS 001	T1 05	30.00	1.0035	0.07	20.83	16.30	48.34
GS 002	T1 30	30.00	1.0066	nd	12.89	6.90	15.66
GS 003	T1 05	55.00	1.0010	nd	22.19	13.25	19.61
GS 004	T1 30	55.00	1.0097	nd	21.67	9.94	343.85
GS 005	T1 05	100.00	1.0058	nd	24.91	12.70	83.84
GS 006	T1 30	100.00	1.0009	nd	19.01	3.65	111.99
GS 007	T1 05	130.00	1.0030	nd	23.21	12.76	17.64
GS 008	T1 30	130.00	1.0061	nd	15.53	8.03	12.60
GS 009	T1 05	175.00	1.0003	nd	24.07	11.67	13.06
GS 010	T1 30	175.00	1.0033	nd	27.24	6.92	126.98
GS 011	T1 05	220.00	1.0052	nd	22.75	11.43	52.27
GS 012	T1 30	220.00	1.0024	nd	12.82	5.83	23.86
GS 013	T1 05	285.00	1.0021	nd	nd	nd	nd
GS 014	T1 30	285.00	1.0021	nd	3.79	3.33	18.04
GS 031	T2 05	35.00	1.0024	nd	17.12	12.21	34.84
GS 032	T2 30	35.00	1.0082	nd	5.24	3.47	1.97
GS 033	T2 05	70.00	1.0066	nd	17.02	10.26	19.12
GS 034	T2 30	70.00	1.0027	nd	8.02	5.26	6.15
GS 035	T2 05	100.00	1.0007	nd	18.12	9.64	10.37
GS 036	T2 30	100.00	1.0061	nd	9.97	4.24	2.73
GS 037	T2 05	155.00	1.0035	nd	17.61	7.39	10.34
GS 038	T2 30	155.00	1.0016	nd	8.31	2.79	7.68
GS 039	T2 05	190.00	1.0009	nd	18.91	8.52	15.75
GS 040	T2 30	190.00	1.0089	nd	11.46	4.32	6.87
GS 041	T2 05	215.00	1.0020	nd	19.61	8.15	17.27
GS 042	T2 30	215.00	1.0096	nd	11.59	2.81	8.76
GS 043	T2 05	260.00	1.0070	nd	12.91	5.63	19.50
GS 044	T2 30	260.00	1.0035	nd	11.70	4.95	21.11

Grainsize Data			Cumulative Weight Percent		
SAMPLE No	weight g	0Ø	2 Ø	4Ø	6Ø
GS 003	6.34	0.00	0.00	0.00	13.33
GS 004	12.04	0.00	0.00	0.00	39.51
GS 005	8.35	0.00	0.00	0.00	11.80
GS 006	17.43	0.00	0.00	0.00	13.92
GS 007	11.07	0.00	0.00	0.00	22.18
GS 008	22.26	0.00	0.00	0.00	6.85
GS 009	4.08	0.00	0.00	0.00	8.70
GS 011	9.17	0.00	0.00	0.00	19.86
GS 013	93.52	0.00	27.79	95.56	97.80
GS 015	1.39	0.00	0.00	0.00	12.19
GS 017	26.30	0.00	0.60	3.60	9.44
GS 019	2.00	0.00	0.00	0.00	12.22
GS 021	8.23	0.00	0.00	0.00	21.32
GS 022	32.34	0.00	0.00	0.00	39.25
GS 023	5.35	0.00	0.00	0.00	8.61
GS 024	36.25	0.00	0.00	2.76	35.57
GS 025	12.92	0.00	0.00	0.00	36.12
GS 029	101.98	0.00	30.01	91.98	95.37
GS 030	135.20	0.00	23.40	80.29	91.28
GS 032	44.30	0.00	0.69	9.82	11.38
GS 034	37.18	0.00	1.18	5.79	11.48
GS 035	6.18	0.00	0.43	3.73	10.61
GS 036	41.64	0.00	0.82	1.22	5.82
GS 037	17.89	0.00	0.82	5.54	14.62
GS 038	27.29	0.00	0.60	1.39	7.00
GS 039	10.62	0.00	1.21	4.75	7.58
GS 041	12.97	0.00	0.44	4.66	12.29
GS 042	24.72	0.00	2.26	5.37	10.63
GS 043	17.15	0.00	2.95	22.90	35.87
GS 044	36.71	0.00	7.36	46.70	58.39
GS 045	21.13	0.00	0.53	3.15	7.98
GS 046	30.31	0.00	4.29	13.85	18.10
GS 048	33.17	0.00	0.20	6.79	19.20
GS 049	25.04	0.00	15.05	66.49	71.72
GS 052	50.63	0.00	20.13	49.03	58.09
GS 054	73.63	0.00	11.83	75.05	83.14
GS 068	65.84	0.00	6.53	59.98	68.87
GS 069	87.87	0.00	28.85	84.02	90.98

SAMPLE No	8Ø	10Ø	>10Ø	% sand	% silt	% clay
GS 003	35.33	58.52	100.00	0.00	58.52	41.48
GS 004	71.50	85.79	100.00	0.00	85.79	14.21
GS 005	41.38	60.42	100.00	0.00	60.42	39.58
GS 006	42.27	61.52	100.00	0.00	61.52	38.48
GS 007	33.92	66.44	100.00	0.00	66.44	33.56
GS 008	26.17	42.05	100.00	0.00	42.05	57.95
GS 009	35.17	57.48	100.00	0.00	57.48	42.52
GS 011	39.12	62.74	100.00	0.00	62.74	37.26
GS 013	98.32	98.68	100.00	95.56	3.12	1.32
GS 015	43.73	93.55	100.00	0.00	93.55	6.45
GS 017	23.72	40.91	100.00	3.60	37.30	59.09
GS 019	30.67	61.60	100.00	0.00	61.60	38.40
GS 021	44.53	68.41	100.00	0.00	68.41	31.59
GS 022	70.03	85.48	100.00	0.00	85.48	14.52
GS 023	29.75	60.90	100.00	0.00	60.90	39.10
GS 024	68.10	84.06	100.00	2.76	81.30	15.94
GS 025	40.30	67.40	100.00	0.00	67.40	32.60
GS 029	97.07	98.78	100.00	91.98	6.81	1.22
GS 030	96.63	99.26	100.00	80.29	18.97	0.74
GS 032	22.93	43.92	100.00	9.82	34.10	56.08
GS 034	26.32	46.66	100.00	5.79	40.87	53.34
GS 035	28.83	53.85	100.00	3.73	50.12	46.15
GS 036	21.57	36.77	100.00	1.22	35.54	63.23
GS 037	28.76	48.19	100.00	5.54	42.65	51.81
GS 038	18.74	32.72	100.00	1.39	31.33	67.28
GS 039	20.53	35.45	100.00	4.75	30.70	64.55
GS 041	26.55	41.89	100.00	4.66	37.23	58.11
GS 042	24.26	42.30	100.00	5.37	36.93	57.70
GS 043	48.78	63.77	100.00	22.90	40.87	36.23
GS 044	69.62	79.31	100.00	46.70	32.61	20.69
GS 045	25.44	42.64	100.00	3.15	39.49	57.36
GS 046	33.51	52.99	100.00	13.85	39.14	47.01
GS 048	40.54	60.15	100.00	6.79	53.35	39.85
GS 049	76.87	82.37	100.00	66.49	15.88	17.63
GS 052	67.21	76.18	100.00	49.03	27.15	23.82
GS 054	92.14	92.34	100.00	75.05	17.29	7.66
GS 068	76.22	82.53	100.00	59.98	22.56	17.47
GS 069	93.57	95.34	100.00	84.02	11.32	4.66

Appendix 2-31

Surfacewater samples

Sample	Location	Cd ppb	Pb ppb	Cu ppb	Hg ppb
WS1	Transect 1 30 m	0.00	3.60	10.72	0.00
WS2	Transect 1 55 m	0.00	3.76	24.76	0.00
WS3	Transect 1 220 m	0.00	2.76	17.92	0.00
WS4	Transect 1 285 m	0.00	6.64	21.16	0.00
WS5	Transect 3 35 m	0.00	4.00	33.28	2.64
WS6	Transect 3 90 m	0.00	3.04	25.16	0.63
WS7	Transect 3 130 m	0.00	2.76	18.28	0.44
WS8	Transect 3 305 m	0.00	3.04	17.96	0.00
WS9	Transect 3 365 m	0.00	3.08	17.92	0.00
WS10	Piesometer 1 8:03 am	0.00	2.08	24.72	0.00
WS11	Piesometer 1 12:26 pm	0.00	2.28	9.04	0.00
WS12	Piesometer 2 12:45 pm	0.00	3.96	11.56	7.72
WS13	Piesometer 3 1:08 pm	0.00	3.36	14.40	0.00
WS14	Piesometer 6 1:30 pm	0.00	4.20	11.20	0.43
WS15	Piesometer 4 1:45 pm	0.00	2.84	9.28	0.00
WS16	Piesometer 1 5:10 pm	0.00	3.36	9.72	0.40
WS17	Piesometer 4 5:26 pm	0.00	2.88	11.88	0.80
WS18	Piesometer 3 5:58 pm	0.00	2.84	14.52	0.40
WS19	Piesometer 6 6:06 pm	0.00	2.36	9.08	0.00
WS20	Transect 2 35 m	0.00	2.60	9.12	0.00
WS21	Transect 2 70m	0.00	3.44	11.36	0.00
WS22	Transect 2 100 m	0.00	2.48	15.24	0.00
WS23	Transect 2 155 m	0.00	2.08	10.56	0.00
WS24	Transect 2 260 m	0.00	2.92	16.60	0.80
WS25	Transect 4 25 m	0.00	1.36	10.64	1.20
WS26	Transect 4 105 m	0.00	1.16	9.88	2.40
WS27	Transect 4 160 m	0.00	2.20	10.00	1.20
WS28	Transect 4 205 m	0.00	1.36	10.52	3.60
WS29	Transect 5 105 m	0.00	1.68	10.80	0.00
WS30	Transect 5 215 m	0.00	1.44	1.04	0.00
WS31	Transect 5 280 m	0.00	0.68	9.88	0.00
WS32	Transect 5 315 m	0.00	1.84	13.40	3.20
WS33	Transect 5 335 m	0.00	1.20	11.92	0.80
WS34	Leachate SE corner of tip and road	0.00	1.08	13.16	0.00
WS35	Leachate midway SE corner and T1	1.44	9.40	18.28	1.20
WS36	Transect 5 405 m	0.00	0.72	15.00	0.00
WS37	Transect 5 435 m	0.00	0.60	14.36	2.80
WS38	Transect 5 470 m	0.00	0.03	13.60	2.40
WS39	Transect 5 580 m	0.00	1.44	6.08	2.80
WS40	Leachate SE corner of tip and road	0.00	1.60	21.48	0.00
WS41	Leachate on road at SE corner of Tip	0.00	2.80	10.00	0.00
WS42	Surface runoff midway SE corner and T1	0.00	6.00	15.60	0.10
WS43	Surface runoff midway T1 and T2	0.00	2.40	8.00	0.20
WS44	Surface runoff midway T2 and T3	0.00	2.00	7.20	0.10
WS45	Leachate from drain SE corner	0.00	2.40	8.00	0.00

Surfacewater samples

Sample	Location	Zn ppb	Cr ppb	Ni ppb	Fe ppm
WS1	Transect 1 30 m	17.84	0.06	7.06	0.20
WS2	Transect 1 55 m	109.74	0.12	5.90	0.18
WS3	Transect 1 220 m	128.72	0.06	6.28	0.25
WS4	Transect 1 285 m	82.47	0.06	4.38	0.25
WS5	Transect 3 35 m	158.41	0.06	6.28	0.39
WS6	Transect 3 90 m	98.18	0.12	9.80	0.27
WS7	Transect 3 130 m	215.18	0.12	7.06	0.55
WS8	Transect 3 305 m	117.11	0.06	4.76	0.19
WS9	Transect 3 365 m	138.24	0.17	7.06	0.33
WS10	Piesometer 1 8:03 am 5/4/91	96.08	0.29	6.28	0.26
WS11	Piesometer 1 12:26 pm 5/4/91	892.33	0.06	5.14	0.53
WS12	Piesometer 2 12:45 pm 5/4/91	111.84	0.12	5.52	0.52
WS13	Piesometer 3 1:08 pm 5/4/91	123.44	0.12	5.14	0.64
WS14	Piesometer 6 1:30 pm 5/4/91	216.26	0.06	5.52	0.99
WS15	Piesometer 4 1:45 pm 5/4/91	443.90	0.17	7.44	0.70
WS16	Piesometer 1 5:10 pm 5/4/91	333.12	0.23	7.83	0.62
WS17	Piesometer 4 5:26 pm 5/4/91	105.53	0.29	6.67	1.07
WS18	Piesometer 3 5:58 pm 5/4/91	146.72	0.17	9.01	1.54
WS19	Piesometer 6 6:06 pm 5/4/91	347.52	0.06	8.22	0.46
WS20	Transect 2 35 m	147.78	0.12	6.67	0.42
WS21	Transect 2 70m	98.18	0.23	7.06	1.78
WS22	Transect 2 100 m	142.48	0.23	6.67	0.88
WS23	Transect 2 155 m	102.38	0.12	7.44	1.10
WS24	Transect 2 260 m	103.43	0.12	8.61	1.34
WS25	Transect 4 25 m	104.48	0.23	9.01	0.60
WS26	Transect 4 105 m	142.48	0.12	5.90	0.96
WS27	Transect 4 160 m	79.33	0.17	6.67	1.78
WS28	Transect 4 205 m	77.24	0.17	7.83	1.54
WS29	Transect 5 105 m	68.90	0.23	7.06	1.66
WS30	Transect 5 215 m	95.03	0.17	9.01	0.80
WS31	Transect 5 280 m	95.03	0.17	7.44	0.79
WS32	Transect 5 315 m	113.95	0.12	8.61	1.20
WS33	Transect 5 335 m	63.69	0.12	10.20	1.24
WS34	Leachate SE corner of tip and road	338.66	0.42	14.25	1.84
WS35	Leachate midway SE corner and T1	4089.38	0.54	77.23	36.31
WS36	Transect 5 405 m	174.41	0.17	9.01	1.41
WS37	Transect 5 435 m	101.33	0.23	9.01	1.80
WS38	Transect 5 470 m	109.74	0.17	8.61	1.39
WS39	Transect 5 580 m	92.93	0.23	8.22	1.86
WS40	Leachate SE corner of tip and road	393.23	0.17	13.02	1.77
WS41	Leachate on road at SE corner of Tip	18.73	0.06	8.91	0.04
WS42	Surface runoff midway SE corner and T1	92.23	0.12	11.40	0.03
WS43	Surface runoff midway T1 and T2	93.30	0.06	10.15	0.33
WS44	Surface runoff midway T2 and T3	25.79	0.06	7.06	0.23
WS45	Leachate from drain SE corner	68.30	0.17	7.06	0.06

Appendix 2-33

Ground water samples

Sample	Cd	Pb	Cu	Hg	Zn	Cr	Ni	Fe
	Values µg/l					LD .16 ppb		
24/6/91								
Pz 1	0.00	2.20	27.04	0.54	9.17	0.16	7.67	434.83
Pz 2	0.00	4.28	22.52	0.36	13.01	0.16	7.06	367.94
Pz 3	0.00	1.96	23.88	0.27	10.69	0.32	4.63	379.68
Pz 4	0.00	2.20	27.12	0.75	16.78	0.16	8.29	274.75
Pz 5	0.00	2.20	21.16	0.60	11.13	0.16	4.63	388.51
Pz 6	0.00	2.52	20.40	0.22	12.03	0.16	4.02	188.17
9/7/91								
Pz 1	0.00	6.80	45.20	0.80	11.47	0.16	7.67	163.39
Pz 2	0.00	18.00	107.60	0.56	32.18	0.00	8.91	151.47
Pz 3	0.00	19.60	804.40	64.14	325.59	0.32	6.45	431.34
Pz 4	0.00	24.00	57.20	0.82	29.00	0.00	10.78	402.30
Pz 5	0.00	68.00	64.80	0.50	16.47	0.00	5.84	393.01
Pz 6	2.40	129.60	72.40	0.75	27.58	0.16	6.45	267.72
24/7/91								
Pz 1	0.00	8.40	52.40	0.48	34.73	0.16	9.53	16.99
Pz 2	0.00	5.60	52.80	1.12	31.57	0.16	7.06	36.36
Pz 3	0.00	21.60	38.80	0.26	16.29	0.16	6.45	13.70
Pz 4	0.00	26.80	62.40	0.14	30.29	0.16	7.67	24.70
Pz 5	0.00	21.20	42.00	0.00	67.29	0.00	4.63	19.19
Pz 6	0.00	10.00	63.20	0.00	68.80	0.00	3.43	15.89
20/8/91								
Pz 1	0.80	6.40	19.60	0.05	5.54	0.00	7.06	72.16
Pz 2	0.00	2.80	31.60	0.00	8.11	0.00	5.84	18.11
Pz 3	0.00	4.80	24.80	0.25	10.09	0.16	7.67	26.92
Pz 4	0.00	11.60	39.20	0.05	718.50	0.32	10.78	28.02
Pz 5	0.00	4.40	27.20	0.00	17.40	0.16	8.91	24.15
Pz 6	0.00	6.40	24.00	0.17	3.91	0.16	7.06	14.24
4/9/91								
Pz 1	0.00	14.40	88.00	7.60	31.04	0.16	7.06	315.24
Pz 2	0.00	9.20	48.40	3.28	17.15	0.00	5.84	12.62
Pz 3	0.00	0.80	187.60	70.98	85.85	0.16	8.29	18.09
Pz 4	0.00	2.00	29.20	0.50	33.25	0.32	7.06	29.68
Pz 5	0.00	4.40	178.80	0.21	36.62	0.32	7.67	16.44
Pz 6	0.00	6.00	16.40	0.00	6.63	0.16	6.45	15.34
20/9/91								
Pz 1	0.00	3.20	19.20	0.00	11.25	0.00	6.45	14.25
Pz 2	0.00	6.00	17.20	0.00	14.59	0.16	5.84	17.54
Pz 3	0.00	2.80	52.40	0.08	23.02	0.16	6.45	20.30
Pz 4	0.00	3.20	90.80	0.55	63.77	0.00	9.53	17.55
Pz 5	0.00	4.00	59.60	0.67	22.48	0.00	8.91	18.64
Pz 6	0.00	9.60	20.80	0.39	128.36	0.00	8.29	24.15

Ground water samples

Sample	Cd	Pb	Cu	Hg	Zn	Cr	Ni	Fe
	Values µg/l					LD .16 ppb		
4/10/91								
Pz 1	0.00	7.20	112.40	0.10	35.75	0.16	7.67	18.78
Pz 2	0.00	5.20	84.40	0.00	11.92	0.32	7.06	26.91
Pz 3	0.00	3.60	20.80	0.00	8.17	0.16	6.45	73.32
Pz 4	0.00	-	-	-	-	-	-	-
Pz 5	0.00	6.00	75.60	0.00	119.21	0.32	8.91	21.94
Pz 6	0.00	4.40	38.80	0.90	8.17	0.32	7.67	24.15
10/11/91								
Pz 1	80.00	340.00	1625.60	2866.11	6327.29	1.61	13.30	463.53
Pz 2	0.00	28.00	29.20	0.00	12.15	0.32	6.45	24.70
Pz 3	0.00	40.00	28.00	0.07	8.22	0.16	6.45	19.19
Pz 4	0.00	-	-		-	-	-	-
Pz 5	0.00	-	-		-	-	-	-
Pz 6	0.00	5.20	155.20	0.60	60.29	0.00	5.23	25.25
31/1/92								
Pz 1	0.00	24.80	16.00	0.00	20.15	0.00	8.29	25.81
Pz 2	0.00	2.80	10.40	0.00	12.03	0.00	7.06	28.02
Pz 3	0.00	1.20	8.00	0.07	7.75	0.00	5.84	21.41
Pz 4	0.00	4.40	22.40	0.00	1.53	0.16	7.06	20.30
Pz 5	0.00	4.40	19.60	0.00	7.29	0.16	5.84	26.91
Pz 6	0.00	2.40	9.20	0.00	0.80	0.00	5.23	23.04
8/2/92								
Pz 1	0.00	6.40	18.80	0.00	19.12	0.00	7.52	24.74
Pz 2	0.00	8.80	12.80	0.00	6.93	0.00	4.07	26.39
Pz 3	0.00	2.00	10.80	0.00	14.00	0.00	5.44	40.26
Pz 4	0.00	2.40	8.40	0.00	2.95	0.16	4.75	35.80
Pz 5	4.40	7.20	12.40	0.11	2.95	0.00	4.75	24.15
Pz 6	0.00	2.00	10.40	0.08	2.49	0.00	5.44	25.80

Appendix 3 - 1

METEOROLOGICAL OBSERVATIONS RECORDED AT BRISBANE AIRPORT

MONTH JANUARY 1991

Date	Temp (°C)		Rel Humidity (%)		Sunshine (hours)	Rainfall (mm)	Wind Dir/Speed km/hr		Max Wind Gust
	Max	Min	9am	3pm			9am	3pm	Dir/Km:Hr/Time
1	29.5	21.5	72	85	10.1	9.6	E 20	E 17	E 45 1352
2	28.8	21.6	85	92	6.5	8.4	E 18	E 20	E 61 0905
3	29.0	23.2	66	56	5.5	1.8	E 28	E 30	E 48 1116
4	28.6	24.1	61	57	3.0		ENE 26	ENE 20	ENE 41 0848
5	27.3	24.5	75	77	0.0		NE 24	NNE 33	N 65 2154
6	31.0	24.6	86	95	6.0	2.0	N 28	NNW 11	SW 57 1252
7	28.1	20.0	65	61	12.2	11.0	S 17	E 28	E 43 1406
8	27.7	20.8	67	56	11.0		SE 19	E 30	E 45 1141
9	28.3	21.4	55	51	9.5		E 26	E 33	E 52 1218
10	27.7	19.9	75	48	10.9	0.4	S 13	E 26	E 45 1257
11	28.7	18.6	67	58	10.1		SSE 31	E 22	ENE 41 1312
12	28.6	19.0	68	51	12.8		E 3	ENE 20	NE 35 1642
13	29.1	19.7	63	47	13.0		SE 13	E 19	NE 41 1308
14	29.4	21.1	59	53	9.6		E 19	NE 22	ENE 33 1502
15	29.4	21.6	66	53	3.0		NE 17	NNE 22	NNE 37 1425
16	31.2	19.6	68	60	3.5		NW 7	E 19	NNE 26 1439
17	27.8	22.4	75	67	0.2		ESE 11	NE 11	E 26 1826
18	27.1	19.9	86	70	2.1	6.6	SSW 9	N 15	N 31 1457
19	30.1	19.7	77	66	12.3	1.2	NW 7	NNE 21	N 43 1801
20	32.0	23.3	80	86	6.5		N 5	NNE 20	SW 54 1614
21	30.9	21.9	86	64	8.1	9.1	NW 5	NNE 22	N 43 1704
22	30.1	20.3	76	71	11.9	3.8	S 13	ENE 19	N 35 1830
23	30.2	23.8	81	70	9.2		SE 9	ENE 20	NE 33 1130
24	32.0	25.4	74	60	6.1		NNW 22	N 30	N 45 1744
25	31.9	24.1	77	69	3.8	1.0	N 20	NNE 24	N 37 1727
26	31.2	24.6	84	71	6.0	2.6	N 13	N 35	N 18 1452
27	30.1	23.0	87	91	2.5	1.1	NNW 11	NNW 9	ESE 43 1853
28	28.3	23.1	63	64	0.1	2.0	SSE 13	E 13	SE 28 0928
29	32.6	21.1	73	53	12.0	0.1	SSW 15	NNE 17	NE 33 1611
30	30.0	24.4	86	65	4.7		SSE 15	ESE 32	ESE 48 1402
31	29.1	21.1	75	63	12.6	20.2	SE 9	ENE 19	NE 31 1456
TOTALS	915.8	679.9	2278	2030	225.1	87.8			
MEANS	29.6	21.9	73	65	7.3				
AVERAGE	29.1	20.9	66	59	8.3	167 mm on 13 days			

The MEAN is the sum of the values for this month divided by the number of days this month.

The AVERAGE is the sum of all the monthly means divided by the number of years of record (ie 1949 to present).

Appendix 3 - 2

METEOROLOGICAL OBSERVATIONS RECORDED AT BRISBANE AIRPORT

MONTH FEBRUARY 1991

Date	Temp (°C)		Rel Humidity (%)		Sunshine (hours)	Rainfall (mm)	Wind Dir/Speed km/hr		Max Wind Gust
	Max	Min	9am	3pm			9am	3pm	Dir/Km:Hr/Time
1	30.7	20.7	72	61	11.5		WSW 11	NE 22	N 41 1639
2	29.4	22.5	67	47	11.9		ESE 26	E 31	SE 52 0913
3	28.7	22.1	57	53	10.4		ESE 22	ENE 24	NE 41 1440
4	29.1	20.2	58	52	11.5		ENE 15	NE 19	ENE 33 1632
5	28.5	20.2	66	66	6.1		ESE 7	ENE 24	ENE 43 1344
6	26.7	22.1	96	93	0.0	24.4	W 7	ENE 15	NNE 52 2320
7	30.2	23.0	88	83	6.6	78.6	N 19	N 37	N 61 1620
8	31.2	23.9	93	77	2.2	11.4	W 6	NNE 17	NNE 45 1653
9	30.0	23.0	85	73	1.7	67.6	S 11	NE 9	SE 30 0028
10	31.2	23.7	81	68	12.3	0.4	SW 20	E 28	E 41 1256
11	32.4	22.6	63	49	12.7		S 19	ESE 24	ESE 48 2003
12	29.2	23.7	88	72	3.1		SSE 15	SE 28	SE 41 1455
13	29.6	22.6	83	62	12.3	14.0	SSE 11	E 22	E 35 1515
14	29.5	23.0	80	64	12.5		SSE 9	NE 20	NE 33 1444
15	29.2	22.8	83	50	11.9		SSE 7	NE 17	NE 31 1325
16	31.6	21.8	78	60	12.6		SSW 17	NNE 13	N 31 1936
17	28.2	24.6	72	64	3.5		SE 28	ESE 31	SE 54 1624
18	26.8	22.0	83	67	0.5		SE 15	ESE 22	ESE 43 1537
19	28.5	19.2	76	53	11.6	0.6	SSW 17	E 24	E 39 1332
20	28.4	18.2	68	43	11.7		S 15	E 20	SSE 45 1021
21	28.4	19.3	62	45	9.3		S 17	SE 26	ESE 41 1219
22	28.3	20.3	69	58	7.6	0.2	S 15	ENE 24	E 39 1305
23	27.3	19.3	73	70	4.5		S 13	S 9	SE 41 1148
24	29.0	19.5	73	47	5.8	2.4	SSE 22	ESE 28	E 45 1425
25	29.3	20.0	86	64	9.8	5.6	S 13	E 24	E 43 1035
26	28.7	19.8	84	49	9.4	2.1	E 11	E 26	E 39 1337
27	29.1	19.7	68	49	11.9	1.0	S 11	E 22	E 45 1329
28	26.9	19.0	71	86	4.6		S 11	ESE 17	ESE 43 1430
TOTALS	816.4	598.8	2123	1725	230.0	208.6			
MEANS	29.2	21.4	76	62	8.2				
AVERAGE	28.9	20.8	69	60	7.6	168 mm on 14 days			

The MEAN is the sum of the values for this month divided by the number of days this month

The AVERAGE is the sum of all the monthly means divided by the number of years of record (ie 1949 to present).

Appendix 3 - 3

METEOROLOGICAL OBSERVATIONS RECORDED AT BRISBANE AIRPORT

MONTH DECEMBER 1991

Date	Temp (°C)		Rel Humidity (%)		Sunshine (hours)	Evaporation (mm)	Rainfall (mm)	Wind Dir/Speed km/hr		Max Wind Gust		
	Max	Min	9am	3pm				9am	3pm	Dir	Km:Hr	Time
1	26.4	18.2	73	65	7.1	8.0	11.4	SSE 13	E 31	E	50	1352
2	25.8	18.6	64	50	9.7	6.4	0.6	ESE 22	E 24	ESE	43	1226
3	26.0	17.5	60	58	10.9	8.6		ESE 13	NE 20	ENE	31	1242
4	28.7	16.5	60	61	11.2	5.8		NNW 11	N 31	N	57	1837
5	28.3	19.0	55	56	9.3	8.0		SSE 20	ESE 35	E	57	1340
6	26.1	19.7	59	53	11.2	10.0		ESE 15	NE 20	ENE	37	1343
7	27.2	18.8	62	55	8.4	8.8		N 19	NE 24	SE	54	1817
8	24.9	17.0	69	73	7.1	12.8	30.6	S 15	NE 13	NE	33	1258
9	26.7	18.9	62	54	12.8	4.4	0.4	NE 19	NE 22	NE	37	1453
10	27.0	19.2	54	55	10.3	9.2		NNE 17	NNE 26	N	45	1539
11	24.2	20.6	94	75	0.0	9.4	2.6	NNW 13	NNE 22	N	52	1331
12	23.9	20.6	96	93	0.0	*N/A	75.0	ENE 31	NNE 26	NE	56	1055
13	28.7	19.4	86	69	10.4	*N/A	58.0	SW 9	NE 20	N	43	1553
14	30.1	21.5	81	64	9.4	5.6		N 13	N 37	N	57	1552
15	33.2	21.2	46	33	13.4	7.2		WSW 20	WSW 26	SW	50	1303
16	33.5	18.5	57	32	11.4	10.2		S 3	NNE 20	N	41	1522
17	29.5	19.4	42	52	12.7	7.6	2.6	SSE 11	NNE 26	NE	39	1451
18	30.6	20.6	62	70	10.8	7.4		N 24	NNE 39	N	76	1835
19	29.7	20.8	64	73	10.0	10.6		N 26	NNE 45	N	57	1452
20	30.0	21.4	73	91	7.3	7.8		NW 9	N 28	N	48	1507
21	31.0	20.5	67	73	8.9	6.6	6.6	NW 13	NNE 22	WSW	72	2127
22	28.0	18.5	70	62	11.2	7.8	10.2	ENE 13	NNE 19	NNE	37	1559
23	26.7	19.0	72	58	9.2	6.8		S 13	E 24	E	39	1642
24	27.7	17.0	58	54	12.5	7.0		SW 13	E 22	E	41	1551
25	28.8	16.3	65	57	12.6	8.0		SW 13	ENE 18	ENE	30	1220
26	29.2	16.8	69	34	12.5	6.6		S 7	ENE 20	E	33	1732
27	29.0	19.5	65	54	12.5	8.6		ESE 11	NE 17	NE	31	1655
28	29.5	20.4	70	48	11.5	8.6		W 3	NNE 22	NNE	35	1617
29	30.2	21.1	68	48	9.7	8.2		S 3	ENE 22	E	37	1508
30	29.6	22.5	89	61	9.4	4.8		ESE 9	ENE 17	E	30	1155
31	29.0	23.4	90	70	6.2	10.4		NW 9	NE 19	N	30	1158
TOTALS	879.2	602.4	2102	1851	299.6	216.2	198.0					
MEANS	28.4	19.4	68	60	9.7							
AVERAGE	28.8	19.9	62	58	8.6	200	125mm on 12 days					

The MEAN is the sum of the values for this month divided by the number of days this month.

The AVERAGE is the sum of all the monthly means divided by the number of years of record (ie 1949 to present).

* Evaporation Not Available - Overflowed in heavy rain.

Appendix 3 - 4

METEOROLOGICAL OBSERVATIONS RECORDED AT BRISBANE AIRPORT

MONTH NOVEMBER 1991

Date	Temp (°C) Max	Min	Rel Humidity (%) 9am	3pm	Sunshine (hours)	Evaporation (mm)	Rainfall (mm)	Wind Dir/Speed km/hr 9am	3pm	Max Wind Gust Dir/Km:Hr/Time
1	27.3	19.0	66	61	10.0	8.0		SSE 7	E 33	E 48 1331
2	25.4	20.2	67	64	0.4	7.6		SSE 18	E 26	E 41 1324
3	25.7	20.2	66	52	7.3	5.8		NNE 15	NNE 22	NE 33 1446
4	27.3	19.6	59	59	10.1	7.2		NW 17	N 30	N 50 1725
5	32.7	17.8	73	53	10.7	7.2		WNW 3	ENE 22	E 39 1306
6	27.8	16.9	57	56	10.5	7.2		E 15	E 22	ESE 37 1519
7	31.2	18.8	80	64	8.8	5.6		NNW 15	N 28	NNE 48 1638
8	30.8	20.4	65	34	2.3	6.2		Calm	SSW 13	SSW 17 1233
9	27.8	20.6	71	52	9.8	5.4		SSE 7	ENE 22	ENE 39 1629
10	27.2	18.3	67	55	11.7	7.8		E 7	ENE 26	ENE 37 1621
11	27.6	20.5	76	69	6.5	8.0		S 13	N 28	NNE 39 1446
12	29.4	20.7	78	70	8.6	6.4		WNW 9	NNE 24	N 45 1536
13	30.5	18.5	71	71	8.3	5.6	0.2	SE 6	ENE 24	SE 45 1635
14	26.4	19.6	56	54	7.2	8.0		SE 6	E 24	ESE 39 1034
15	25.3	18.5	74	56	3.7	7.4	0.2	SE 17	E 22	E 41 1337
16	25.8	19.0	56	50	4.1	6.8		NNE 17	NE 22	N 43 2249
17	27.6	17.6	71	54	12.3	6.0	0.4	SSW 13	E 35	E 50 1507
18	26.8	20.2	54	52	9.5	8.8		E 11	ENE 22	ENE 35 1654
19	26.4	18.0	56	51	12.5	8.0		SE 11	E 17	E 35 1308
20	27.6	15.3	56	50	11.7	8.2		NNW 13	N 26	N 48 1621
21	27.9	21.6	64	66	3.4	9.6		N 20	E 19	SE 39 1948
22	25.4	17.3	71	44	7.7	6.0	1.6	SSE 22	SE 33	SE 61 1649
23	25.5	15.0	54	42	11.4	8.8		SE 15	E 22	E 43 1406
24	26.1	16.0	59	49	10.7	9.0		SSE 9	ENE 24	NE 35 1438
25	26.9	18.3	72	57	10.0	8.0		E 24	NNE 24	NNE 39 1112
26	27.9	16.3	62	52	8.4	7.2		W 9	NNE 24	NNE 41 1401
27	28.4	17.0	61	50	11.1	8.0		NW 5	N 18	N 50 1535
28	24.8	20.3	90	68	0.2	8.8	3.6	SSE 3	ESE 7	E 33 1754
29	27.9	17.8	70	58	11.7	2.4		NNE 5	NNE 17	N 50 1615
30	28.7	18.4	75	61	9.3	9.4	25.4	NW 5	N 16	W 69 1845
TOTALS	826.1	557.7	1997	1674	249.9	218.4	31.4			
MEANS	27.5	18.6	66	56	8.3					
AVERAGE	27.3	18.0	59	55	8.5	179	98mm on 10 days			

The MEAN is the sum of the values for this month divided by the number of days this month.

The AVERAGE is the sum of all the monthly means divided by the number of years of record (ie 1949 to present).

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METEOROLOGICAL OBSERVATIONS RECORDED AT BRISBANE AIRPORT

MONTH OCTOBER 1991

Date	Temp (°C)		Rel Humidity (%)		Sunshine (hours)	Evaporation (mm)	Rainfall (mm)	Wind Dir/Speed km/hr		Max Wind Gust		
	Max	Min	9am	3pm				9am	3pm	Dir	Km:Hr	Time
1	25.2	14.9	55	32	11.2	8.2		E 13	N 20	ENE	31	1050
2	25.6	12.9	64	57	11.0	7.8		NW 9	NNE 22	N	33	1643
3	25.4	14.2	74	54	11.0	4.8		ENE 13	NNE 17	ENE	28	0848
4	25.4	16.2	54	62	8.4	5.8		E 15	E 22	ENE	39	1136
5	24.9	17.4	49	50	10.9	5.8		E 18	NE 20	NE	35	1138
6	24.9	14.3	55	47	11.2	7.2		SW 11	ENE 22	ENE	33	1440
7	25.9	12.2	53	60	10.7	7.2		N 20	N 31	N	45	1606
8	28.2	18.0	53	84	9.0	6.6	0.4	SW 5	N 24	N	50	1347
9	27.3	17.7	61	51	10.4	4.8	2.8	E 13	SE 31	ESE	54	1557
10	23.2	16.9	68	68	2.4	7.8	0.2	SSE 19	E 15	SE	37	0807
11	25.9	15.5	59	59	9.4	3.0		SE 9	ESE 31	ESE	50	1555
12	24.8	17.8	56	54	8.4	6.6		ESE 13	NE 20	NE	33	1309
13	27.7	13.6	58	51	10.9	6.0		NW 9	NNE 24	N	37	1604
14	25.7	18.6	49	56	10.2	7.4		ESE 19	NE 26	E	39	0936
15	25.6	18.0	60	57	7.5	7.6		N 15	NNE 22	NNE	41	1538
16	27.9	16.8	64	65	10.8	7.2		N 20	N 43	N	59	1431
17	25.3	19.4	55	58	1.1	8.0		ESE 26	SE 31	ESE	61	1646
18	22.2	15.2	82	64	0.3	7.6	6.6	S 11	ESE 22	ESE	48	1358
19	24.9	13.8	62	59	9.2	3.6		S 19	E 30	E	41	1337
20	24.4	15.2	61	62	6.2	7.2		SSE 11	ENE 26	ESE	39	1021
21	25.3	17.7	53	47	11.8	6.8		NE 17	N 25	N	37	1355
22	29.1	14.7	57	39	9.5	6.4		WNW 5	NNE 28	NNE	41	1534
23	23.4	20.5	65	65	0.0	6.0	0.6	SE 20	ESE 22	E	45	1024
24	23.1	16.9	67	73	0.0	5.0	4.6	E 13	ENE 9	SE	35	0104
25	26.6	16.9	75	61	6.9	2.4	9.8	N 17	NNE 26	N	41	1534
26	32.5	15.0	70	15	12.1	4.8	1.6	SE 3	WSW 37	W	63	1518
27	26.1	14.4	66	54	11.6	10.0		SSW 7	ENE 24	SE	45	2029
28	23.8	13.9	43	46	11.3	7.2		S 19	ENE 24	E	41	1314
29	23.5	14.4	58	60	8.7	8.6		SE 17	E 20	ENE	35	1132
30	24.0	14.7	71	55	3.4	5.4		SE 7	NE 20	NNE	31	1349
31	25.6	13.7	61	61	11.0	5.0		NW 13	NNE 33	N	48	1506
TOTALS	793.4	491.4	1878	1726	256.5	197.8	26.6					
MEANS	25.6	15.9	61	56	8.3							
AVERAGE	25.7	15.7	59	52	8.5	162	97 mm on 10 days					

The MEAN is the sum of the values for this month divided by the number of days this month.

The AVERAGE is the sum of all the monthly means divided by the number of years of record (ie 1949 to present).

METEOROLOGICAL OBSERVATIONS RECORDED AT BRISBANE AIRPORT

MONTH SEPTEMBER 1991

Date	Temp (°C) Max	Temp (°C) Min	Rel Humidity (%) 9am	Rel Humidity (%) 3pm	Sunshine (hours)	Evaporation (mm)	Rainfall (mm)	Wind Dir/Speed km/hr 9am	Wind Dir/Speed km/hr 3pm	Max Wind Gust Dir/Km:Hr/Time
1	24.0	8.0	32	13	11.1	8.8		SW 20	SW 17	WSW 48 1153
2	21.7	8.8	47	36	11.0	6.6		SSW 17	NNE 13	NE 28 1224
3	22.4	6.7	33	34	10.5	4.6		SSW 19	E 20	ESE 35 1605
4	23.3	11.0	52	25	10.4	4.8		S 17	NNE 20	ENE 28 1329
5	24.2	9.3	52	40	10.5	5.4		WSW 9	NNE 22	NE 33 1316
6	24.9	7.7	59	43	10.2	5.2		WSW 7	ENE 22	E 37 1549
7	23.9	12.5	58	47	10.7	4.8		SSW 13	NE 17	ENE 30 1542
8	23.6	11.3	69	49	10.5	5.4		SSW 13	NNE 22	NNE 33 1514
9	23.7	10.4	54	56	9.8	4.8		N 11	N 32	N 43 1355
10	24.8	11.0	61	62	8.4	5.8.		N 18	N 47	N 63 1524
11	24.3	15.5	34	29	9.6	8.4		WSW 39	SW 39	W 63 1350
12	23.2	8.9	29	21	10.8	11.6		WSW 37	WSW 37	WSW 69 1122
13	20.0	6.0	30	23	10.9	12.0		SSW 17	NNE 19	SW 31 0001
14	22.1	6.8	41	33	10.7	6.0		WSW 9	N 24	N 37 1605
15	24.4	8.1	56	69	9.5	4.6		NNW 7	N 35	N 57 1629
16	28.6	13.0	49	52	10.2	5.4		WNW 9	N 24	N 35 1310
17	32.6	11.2	74	24	8.0	5.4		N 22	SW 48	WSW 69 1431
18	26.5	12.6	25	19	10.6	11.8		WSW 31	W 31	WSW 61 1413
19	28.1	11.7	28	16	10.7	10.2		W 17	W 28	WSW 59 1306
20	25.3	10.0	24	21	10.8	11.0		SW 13	NE 19	N 43 1733
21	27.1	5.0	31	41	10.7	5.8		WSW 5	N 26	N 43 1630
22	30.0	10.8	20	39	10.8	5.6		WNW 11	SE 31	ESE 54 1534
23	23.2	12.1	52	53	10.6	8.4		ESE 7	ENE 22	ENE 33 1228
24	25.3	15.1	67	63	9.5	5.4		NNE 5	NE 22	ENE 33 1335
25	24.2	18.4	73	52	6.1	6.0	0.2	ENE 13	NNE 28	N 39 1607
26	26.0	13.0	58	73	7.7	5.2		N 19	N 31	N 56 1257
27	26.0	16.7	67	67	9.9	5.2	2.4	NW 5	E 24	E 33 1320
28	28.0	17.8	67	60	10.0	4.0		SW 15	N 20	N 41 1526
29	32.3	10.8	30	13	10.4	7.6		SW 7	W 28	WSW 56 1450
30	30.3	12.8	27	22	10.5	8.0		SW 20	NE 19	ESE 43 1608
TOTALS	764.0	333.0	1399	1195	301.1	203.8	2.6			
MEANS	25.5	11.1	47	40	10.0					
AVERAGE	23.8	12.6	60	47	9.0	136	33mm on 7 days			

The MEAN is the sum of the values for this month divided by the number of days this month.

The AVERAGE is the sum of all the monthly means divided by the number of years of record (ie 1949 to present).

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METEOROLOGICAL OBSERVATIONS RECORDED AT BRISBANE AIRPORT

MONTH AUGUST 1991

Date	Temp (°C) Max	Temp (°C) Min	Rel Humidity (%) 9am	Rel Humidity (%) 3pm	Sunshine (hours)	Evaporation (mm)	Rainfall (mm)	Wind Dir/Speed km/hr 9am	Wind Dir/Speed km/hr 3pm	Max Wind Gust Dir/Km:Hr/Time
1	24.7	6.5	54	21	10.2	3.4		SSE 3	W 37	WSW 57 1438
2	22.0	6.7	52	34	10.2	5.4		SW 18	ENE 11	SW 33 0922
3	21.5	7.3	61	45	10.4	4.2		SSW 15	NE 18	NNE 28 1221
4	22.3	7.2	74	51	9.9	3.4		SSW 9	NE 17	N 31 2232
5	22.8	9.4	78	69	9.1	2.8		WNW 4	N 39	N 54 1549
6	27.9	12.7	75	32	8.2	4.0		N 20	WSW 22	W 48 1124
7	23.2	11.6	38	31	7.8	8.0		SSW 20	N 19	WSW 28 0159
8	22.9	8.5	27	16	10.4	4.0		WSW 24	W 35	WSW 56 1502
9	21.0	10.1	33	13	10.6	9.6		WSW 24	SW 22	SW 45 1053
10	19.7	8.7	36	35	10.4	6.8		SSW 22	E 22	E 39 1523
11	21.2	10.6	53	47	9.0	5.4		SSW 17	E 24	SE 35 1106
12	21.6	11.2	61	41	10.5	3.8		SSW 19	NE 15	SSW 26 0747
13	21.5	9.1	72	52	10.3	3.4		SSW 11	N 28	N 35 1502
14	25.6	6.8	69	17	10.0	4.0		WSW 5	W 17	W 41 1408
15	24.3	7.3	43	22	10.7	4.8		SW 15	W 19	WSW 35 1505
16	23.2	9.7	33	21	10.8	7.2		SW 19	WSW 22	SW 48 1019
17	20.4	12.0	52	46	5.4	5.2		SSE 17	ESE 24	SE 37 1026
18	20.5	11.5	58	51	7.0	5.6		SSE 15	E 20	SE 37 1001
19	21.3	10.1	70	53	9.6	3.0		SSW 15	ENE 9	ENE 30 1405
20	23.0	7.3	72	57	10.6	3.0		W 5	N 33	N 48 1451
21	26.2	14.5	36	15	10.7	5.0		NW 19	WSW 30	WSW 56 1059
22	23.0	6.2	35	24	10.9	9.0		SW 9	NE 15	NE 30 1320
23	22.8	5.2	45	54	10.5	5.0		WSW 11	N 24	N 41 1542
24	23.4	11.3	31	22	10.9	4.0		W 30	WSW 52	WSW 81 1340
25	18.5	7.7	31	26	10.9	11.2		SSW 20	ENE 18	SW 35 0356
26	20.2	6.8	49	48	5.4	4.8		SW 19	ENE 13	SSW 28 0818
27	21.3	8.3	62	48	10.6	3.2		SSW 13	NNE 20	NE 30 1412
28	24.3	7.2	65	64	10.3	3.4		N 13	N 39	N 56 1408
29	26.4	13.0	67	61	9.1	4.8		NW 15	N 22	N 31 1110
30	22.3	13.1	72	31	2.1	4.0		WSW 5	W 20	WSW 31 1429
31	23.7	6.7	24	13	11.0	4.0		SW 19	W 20	W 39 1442
TOTALS	702.7	284.3	1628	1160	293.5	155.4	Nil			
MEANS	22.7	9.2	53	37	9.5					
AVERAGE	21.7	10.1	63	44	8.3	103	45 mm on 7 days			

The MEAN is the sum of the values for this month divided by the number of days this month.

The AVERAGE is the sum of all the monthly means divided by the number of years of record (ie 1949 to present).

METEOROLOGICAL OBSERVATIONS RECORDED AT BRISBANE AIRPORT

MONTH JULY 1991

Date	Temp (°C) Max	Temp (°C) Min	Rel Humidity (%) 9am	Rel Humidity (%) 3pm	Sunshine (hours)	Rainfall (mm)	Wind Dir/Speed km/hr 9am	Wind Dir/Speed km/hr 3pm	Max Wind Gust Dir/Km:Hr/Time
1	22.4	9.0	57	52	8.2		SSW 18	E 16	E 30 1501
2	21.4	11.2	71	55	9.3		SSW 15	ESE 20	E 35 1415
3	21.4	12.1	78	55	7.5		WSW 7	SE 26	SE 43 1633
4	21.1	12.2	75	56	9.6	0.4	SSW 15	SE 17	SE 33 1224
5	20.7	14.0	93	61	6.2	2.0	SSW 13	NE 13	NNE 22 1328
6	23.2	9.2	89	66	8.9		SSW 5	NNE 17	N 26 1625
7	21.9	8.6	61	55	8.7		SSW 11	E 17	ESE 22 1308
8	22.7	12.0	81	65	5.3		SSW 13	ENE 15	NE 28 1524
9	18.6	15.8	90	98	0.0	1.6	ENE 9	NE 11	WSW 50 2351
10	16.5	10.3	60	34	10.2	34.6	WSW 33	WSW 45	WSW 72 1256
11	17.3	11.2	47	36	9.9		W 30	WSW 35	WSW 91 1231
12	20.2	10.3	58	48	10.0		SW 22	WSW 22	WSW 39 1750
13	20.6	8.2	63	52	8.5		SW 18	WSW 7	SW 41 2241
14	18.7	6.3	57	36	10.1		SSW 13	WSW 30	SW 50 0934
15	19.1	7.0	60	38	10.2		WSW 22	WSW 28	WSW 54 1649
16	19.2	6.2	65	38	10.2		SSW 19	N 9	SSW 22 0854
17	19.8	3.7	65	34	9.6		SSW 15	NE 13	SSW 28 1027
18	21.0	3.0	64	21	10.0		S 3	WSW 13	W 31 1339
19	23.7	4.6	57	43	10.0		SSW 13	N 17	SSW 22 1055
20	24.9	4.4	55	20	9.4		SSW 11	WSW 24	WSW 39 1433
21	24.5	4.3	63	22	9.6		WSW 1	NW 7	WSW 31 1240
22	19.6	6.0	76	80	0.6		CALM	NE 5	N 37 1802
23	20.5	12.5	64	41	9.8	1.4	W 28	WSW 41	WSW 70 1059
24	18.4	3.0	43	22	10.3	0.2	WSW 17	W 20	W 30 1355
25	18.1	3.7	54	22	10.2		S 13	SSE 9	WSW 33 0336
26	17.8	4.9	43	26	10.3		SSW 26	SSW 18	SW 37 0847
27	18.6	6.0	52	45	10.1		SSW 18	NNE 15	SSW 28 0857
28	20.5	5.0	60	18	10.2		S 9	WSW 22	SSW 30 1109
29	20.7	5.3	51	27	10.2		SW 15	NW 7	NW 35 1453
30	20.3	5.4	49	34	10.2		SSW 15	N 15	SW 28 0923
31	21.2	3.3	64	26	10.2		SW 5	WSW 20	WSW 33 1339
TOTALS	634.6	238.7	1965	1326	273.5	40.2			
MEANS	20.5	7.7	63	43	8.8				
AVERAGE	20.6	9.5	67	47	7.4	67 mm on 7 days			

The MEAN is the sum of the values for this month divided by the number of days this month.

The AVERAGE is the sum of all the monthly means divided by the number of years of record (ie 1949 to present).

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METEOROLOGICAL OBSERVATIONS RECORDED AT BRISBANE AIRPORT

MONTH JUNE 1991

Date	Temp (°C)		Rel Humidity (%)		Sunshine (hours)	Rainfall (mm)	Wind Dir/Speed km/hr		Max Wind Gust		
	Max	Min	9am	3pm			9am	3pm	Dir	Km:Hr	Time
1	22.5	14.0	80	58	9.2	0.8	SSW 15	E 17	S	30	1040
2	23.0	12.2	78	50	8.9		S 15	ENE 17	NNE	26	1314
3	23.0	10.6	76	48	8.8		SSW 13	NNE 19	N	30	1259
4	21.3	11.9	76	65	2.9		SSE 11	SSE 9	SW	28	0814
5	18.5	16.6	96	96	0.0	7.2	SSE 9	SSW 7	SW	26	1300
6	21.5	16.5	94	98	2.5	43.8	SSW 22	S 7	SE	43	1131
7	22.5	17.1	90	84	1.7	20.2	SSW 13	ESE 13	SSW	22	0719
8	23.3	14.2	80	52	10.0	8.2	SW 17	WSW 22	WSW	35	1025
9	22.2	11.1	73	61	7.1		SW 15	S 9	SW	28	1001
10	21.9	12.8	78	57	9.3		WSW 15	WSW 13	SSW	28	1025
11	22.2	9.5	83	50	8.6		WSW 7	W 11	SW	26	0920
12	22.6	8.0	68	38	10.0		NW 5	SSW 9	SSW	20	1218
13	18.5	9.2	65	41	9.8	1.0	W 9	SW 26	WSW	63	1543
14	20.9	10.5	56	39	10.0		SW 22	WSW 22	WSW	37	0209
15	23.1	11.0	63	50	9.6		SSW 13	SSW 7	SSW	26	0940
16	24.2	10.4	83	28	10.0		NW 7	WSW 16	WSW	31	1209
17	24.7	10.0	60	27	10.0		WSW 9	WSW 24	SW	43	1157
18	21.6	7.4	60	49	9.3		SSW 15	ENE 17	SW	28	0007
19	22.4	9.5	64	63	8.4		SSW 15	NNE 11	SSW	26	0929
20	22.3	13.5	88	72	2.2		CALM	N 15	N	22	1251
21	23.6	14.6	94	67	3.5		SW 7	NNE 15	NW	33	1137
22	22.7	14.0	76	23	9.4	3.8	WSW 22	S 24	S	39	1506
23	21.8	10.0	50	43	9.7		SSW 20	S 5	SW	31	0904
24	25.3	5.3	71	18	8.7		W 5	WNW 13	WSW	37	1127
25	24.1	8.7	33	38	10.0		SSW 13	ENE 15	SSW	28	0934
26	27.2	9.5	72	24	9.0		SSW 5	W 11	WSW	26	1357
27	24.0	6.2	60	46	9.2		SSW 11	ESE 18	ESE	30	1422
28	23.4	13.1	80	56	8.6		SSW 13	NNE 11	N	26	1310
29	25.7	10.0	85	42	8.8		W 5	NW 13	NW	33	1209
30	22.0	8.5	50	33	9.6		SW 11	E 15	SSW	22	0959
TOTALS	682.0	335.9	2182	1516	234.8	85.0					
MEANS	22.7	11.2	73	51	7.8						
AVERAGE	21.2	11.1	69	50	7.2	76 mm on 8 days					

The MEAN is the sum of the values for this month divided by the number of days this month.

The AVERAGE is the sum of all the monthly means divided by the number of years of record (ie 1949 to present).

METEOROLOGICAL OBSERVATIONS RECORDED AT BRISBANE AIRPORT

MONTH MAY 1991

Date	Temp (°C) Max	Temp (°C) Min	Rel Humidity (%) 9am	Rel Humidity (%) 3pm	Sunshine (hours)	Rainfall (mm)	Wind Dir/Speed km/hr 9am	Wind Dir/Speed km/hr 3pm	Max Wind Gust Dir/Km:Hr/Time
1	25.1	14.1	69	49	6.9		SW 11	NE 15	NNE 26 1324
2	27.4	14.0	67	57	9.5		W 9	N 24	N 35 1623
3	27.3	15.9	63	51	10.3		SSW 15	ESE 28	ESE 43 1314
4	24.0	15.9	67	52	10.1		SSE 19	ESE 30	ESE 50 1446
5	24.8	15.2	64	49	8.5		SSW 20	E 22	E 39 1506
6	24.1	15.8	70	55	6.6		SSW 15	E 19	E 28 1247
7	25.0	13.3	70	50	10.4		SSW 15	ENE 17	NE 30 1327
8	25.3	16.0	69	53	7.9	0.8	S 7	NE 11	NE 24 1350
9	26.5	14.5	67	53	8.6		CALM	NE 13	NNE 30 1422
10	24.0	16.4	73	75	5.6		S 3	ESE 13	SSE 33 1505
11	23.2	13.6	60	49	8.7	3.0	S 13	SSE 20	ESE 45 1140
12	23.5	13.3	60	43	10.1		SSW 15	S 3	SSW 31 1314
13	23.8	13.4	60	52	9.8		SSW 15	ESE 22	SE 35 1248
14	21.7	14.0	80	66	2.7		NNE 5	ESE 16	ESE 28 1304
15	20.4	15.3	85	74	0.3	0.2	SSW 11	E 11	SSW 28 0251
16	18.4	14.7	96	83	0.0	14.2	S 19	SSW 15	SSE 37 1048
17	23.3	15.5	84	53	4.8	32.6	SSW 17	SSE 24	SSE 41 1551
18	21.4	16.5	72	68	0.0		S 15	SSE 22	ESE 39 1159
19	23.9	17.0	80	67	4.8		S 15	ESE 19	ESE 35 1028
20	22.7	17.6	85	66	0.9	4.0	S 9	NE 17	NE 37 1017
21	24.0	17.1	83	55	4.0	1.0	S 13	ENE 17	ENE 37 1240
22	23.2	17.7	94	79	4.5	6.4	SW 5	ENE 17	NE 33 1710
23	22.3	17.3	98	71	1.1	3.2	NNE 9	NNW 11	NE 33 1046
24	23.5	18.6	96	67	2.0	0.4	CALM	NNE 9	NE 28 1019
25	23.6	16.5	92	64	2.0	0.2	S 9	N 17	NNE 26 1420
26	24.5	15.3	85	60	9.7		S 11	NNE 11	SSW 20 0548
27	25.0	14.9	92	60	9.8		SSW 15	NE 17	SSW 26 0824
28	24.6	15.9	86	68	4.1		S 5	E 22	E 33 1335
29	22.5	17.0	86	65	3.1	16.2	SSE 13	ESE 17	E 28 1429
30	22.9	14.8	72	57	9.1		SSW 19	ESE 17	S 31 1211
31	23.0	15.2	69	57	7.7		S 17	SE 20	SE 52 1052
TOTALS	734.9	479.3	2394	1868	183.6	82.2			
MEANS	23.7	15.5	77	60	5.9				
AVERAGE	23.5	13.6	70	52	6.5	85 mm on 11 days			

The **MEAN** is the sum of the values for this month divided by the number of days this month.
The **AVERAGE** is the sum of all the monthly means divided by the number of years of record (ie 1949 to present).

METEOROLOGICAL OBSERVATIONS RECORDED AT BRISBANE AIRPORT

MONTH APRIL 1991

Date	Temp (°C)		Rel Humidity (%)		Sunshine (hours)	Rainfall (mm)	Wind Dir/Speed km/hr		Max Wind Gust		
	Max.	Min	9am	3pm			9am	3pm	Dir	Km:Hr	Time
1	29.9	18.1	65	43	9.2		WSW 9	N 26	N	35	1515
2	32.1	17.8	60	47	9.6		SSW 13	E 33	ESE	48	1455
3	26.7	20.0	75	63	6.6		SE 19	ESE 28	ESE	52	1603
4	27.6	17.1	63	57	8.8		SSE 13	E 31	ENE	43	1254
5	27.2	16.7	64	51	11.0		SSW 17	E 39	E	33	1226
6	26.8	16.4	65	50	10.9		S 13	E 22	E	35	1445
7	28.0	16.8	70	51	11.0		SSW 13	NNE 17	NNE	28	1518
8	27.9	18.2	63	51	9.2		SSE 19	SE 22	ESE	54	1417
9	25.6	18.8	77	49	6.2	0.2	SSE 24	SE 28	SE	56	1116
10	26.0	16.2	78	51	8.9	0.4	S 22	ESE 28	E	50	1249
11	25.8	16.0	72	49	10.2	0.2	SSE 22	E 30	E	45	1407
12	26.4	14.7	63	47	10.7	0.2	S 15	E 20	E	37	1222
13	26.1	15.4	73	49	9.7	0.8	SSW 15	E 26	E	39	1449
14	25.8	15.1	73	49	9.9		S 19	NE 19	S	28	0838
15	27.3	14.1	73	55	7.2		W 5	N 22	N	35	1638
16	26.1	17.5	71	55	10.4	1.2	SSE 15	E 24	E	45	1209
17	25.7	15.8	69	61	8.1		SSW 13	ENE 20	NE	28	1344
18	27.9	14.2	66	55	10.7		SW 13	NNE 20	N	31	1300
19	26.1	16.2	66	62	10.6		S 18	NE 18	ENE	31	1406
20	25.9	15.0	72	55	7.6		SSW 13	NNE 17	NE	26	1317
21	26.9	16.5	71	55	10.3		SSW 13	NNE 20	N	33	1635
22	29.0	13.2	63	48	9.4		SSW 15	E 31	E	50	1636
23	24.4	15.8	63	60	10.2		SE 17	NE 15	NE	30	1215
24	30.1	13.2	70	60	9.9		NW 15	NNE 26	N	43	1638
25	27.5	12.6	48	68	9.6		S 7	NNE 24	N	39	1651
26	26.6	18.4	37	22	10.4		WSW 31	WSW 28	W	54	1022
27	26.7	12.0	34	23	10.7		SW 26	S 15	SW	41	1014
28	25.2	12.8	56	51	10.0		SSW 13	E 28	E	45	1424
29	25.2	15.0	56	43	10.4		SSW 15	ENE 22	ESE	43	1922
30	24.8	15.1	62	59	9.3		S 17	E 22	E	39	1121
TOTALS	807.3	474.7	1938	1539	286.7	3.0					
MEANS	26.9	15.8	65	51	9.6						
AVERAGE	26.5	17.1	71	56	7.3	94 mm on 11 days					

The MEAN is the sum of the values for this month divided by the number of days this month.

The AVERAGE is the sum of all the monthly means divided by the number of years of record (ie 1949 to present).

METEOROLOGICAL OBSERVATIONS RECORDED AT BRISBANE AIRPORT

MONTH MARCH 1991

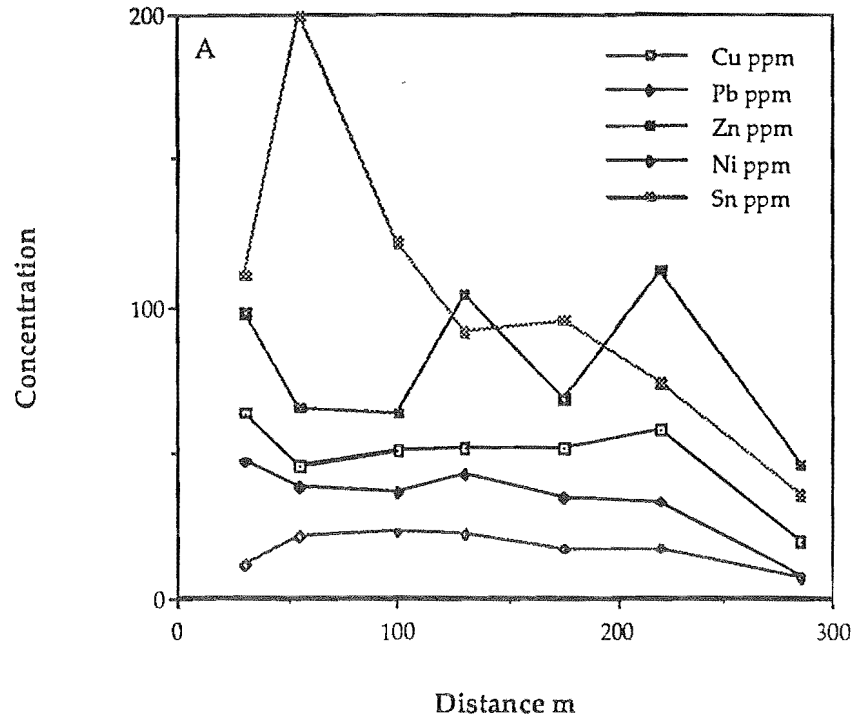
Date	Temp (°C)		Rel Humidity (%)		Sunshine (hours)	Rainfall (mm)	Wind Dir/Speed km/hr		Max Wind Gust Dir/Km:Hr/Time
	Max	Min	9am	3pm			9am	3pm	
1	29.3	18.8	78	63	9.9	1.0	SSW 09	NNE 24	N 39 1627
2	26.0	21.9	75	59	0.5	4.0	SE 17	SE 30	SE 54 1423
3	25.9	17.8	67	66	5.3		S 13	SE 19	SE 57 1308
4	26.6	18.0	83	67	4.1	1.4	SE 22	E 20	E 45 1156
5	28.0	18.2	61	50	8.9	1.8	SE 17	E 20	E 43 1237
6	28.3	19.8	54	55	7.9	0.2	ESE 24	ESE 28	ESE 43 1537
7	28.2	20.4	67	56	9.6	2.0	E 24	E 31	SE 56 1834
8	28.2	19.0	66	62	9.5	2.0	E 24	E 24	ESE 41 1525
9	28.0	19.0	69	62	7.4	1.8	ENE 24	ENE 30	ENE 48 1047
10	27.7	19.0	82	61	5.8		SSE 9	E 15	ENE 41 1055
11	28.0	18.8	70	35	11.0	0.4	SSE 7	ENE 20	ENE 31 1218
12	29.3	17.7	61	50	11.2		SSW 13	NE 20	NNE 30 1608
13	25.9	20.3	74	63	1.8	1.4	SE 15	ESE 20	SE 39 1612
14	27.7	18.5	78	65	9.8	0.8	SE 13	ESE 26	E 43 1545
15	26.5	17.5	80	70	6.4		SSE 13	E 22	ESE 35 1104
16	27.3	17.0	80	70	10.5	1.2	SSW 11	E 20	E 33 1137
17	28.1	17.3	75	74	10.0		SSW 17	E 26	E 41 1529
18	28.5	17.6	76	70	10.8		SSW 15	E 28	ENE 21 1251
19	28.0	18.1	68	65	10.4		S 15	ENE 19	NE 30 1336
20	27.7	17.3	74	64	11.0		SSE 7	NNE 19	N 30 1152
21	28.1	17.9	68	68	11.1		S 11	NE 20	NNE 33 1355
22	30.2	18.3	69	54	10.7		WNW 4	NE 15	NE 30 1703
23	28.4	19.9	36	42	11.0		S 15	E 26	E 41 1523
24	27.5	16.4	59	54	10.3		SSW 13	NE 19	ENE 31 1526
25	29.1	18.7	62	64	9.4		NW 13	NNE 22	N 48 1735
26	29.7	19.0	86	52	9.8		WSW 6	NNE 20	N 37 1550
27	31.0	20.5	81	61	9.6		NW 4	NE 15	NE 26 1308
28	29.7	20.9	66	60	7.6		SE 11	E 26	ESE 45 1859
29	28.2	20.2	79	60	9.5	5.8	SSE 11	E 13	E 41 1232
30	27.8	18.5	68	59	5.0		SW 1	NNE 17	N 30 1247
31	29.0	20.9	87	48	2.0	2.2	CALM	W 11	WSW 39 1211
TOTALS	871.9	583.2	2199	1849	257.8	26.0			
MEANS	28.1	18.8	71	60	8.3				
AVERAGE	28.2	19.6	71	59	7.6	144 mm on 14 days			

The MEAN is the sum of the values for this month divided by the number of days this month.

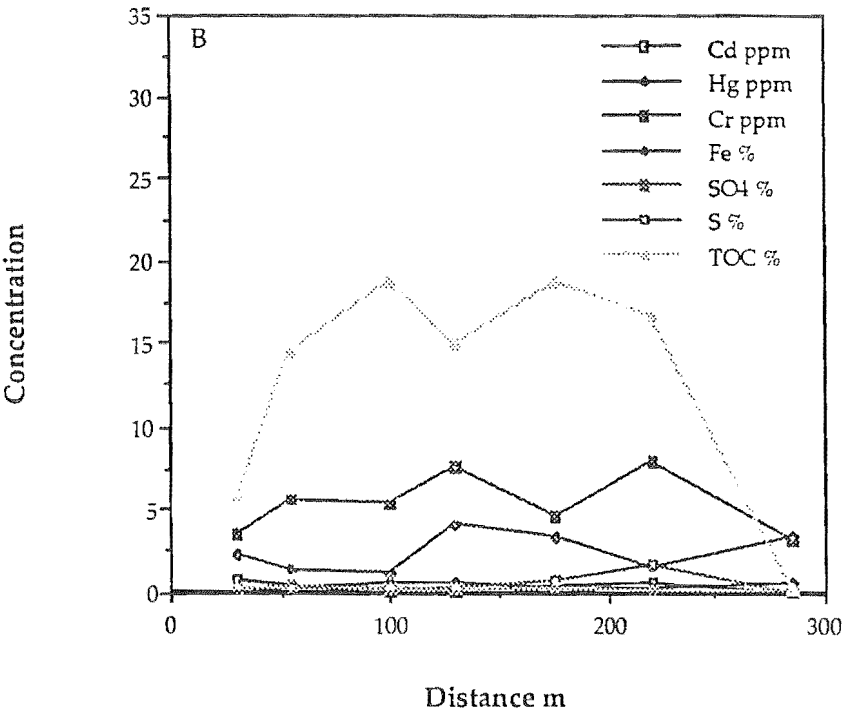
The AVERAGE is the sum of all the monthly means divided by the number of years of record (ie 1949 to present).

Appendix 4 - 1

Data from transect 1 of the top 5 cm
for high concentration metals

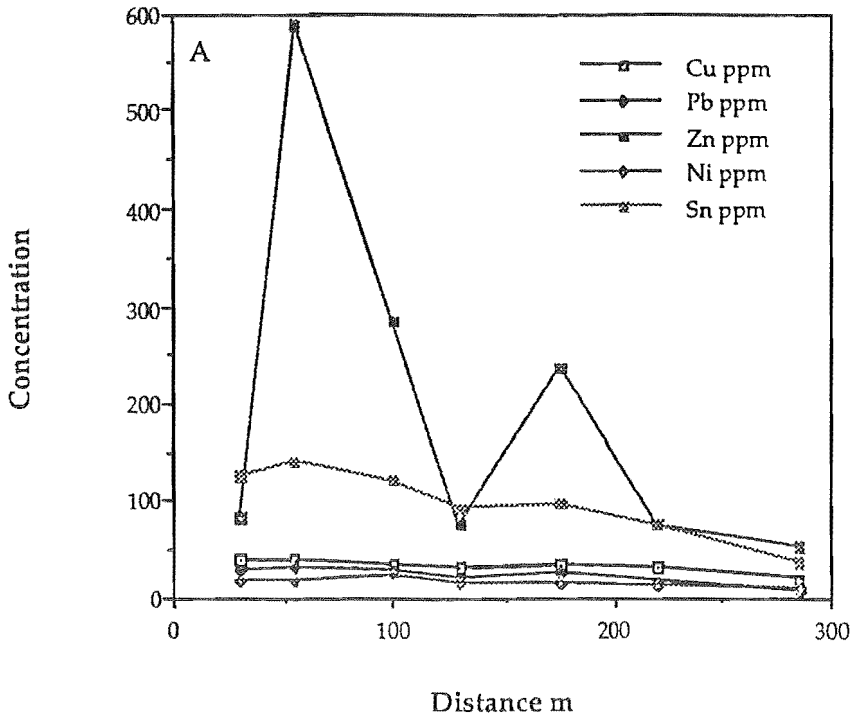


Data from transect 1 of the top 5 cm
for low concentration metals and anions.

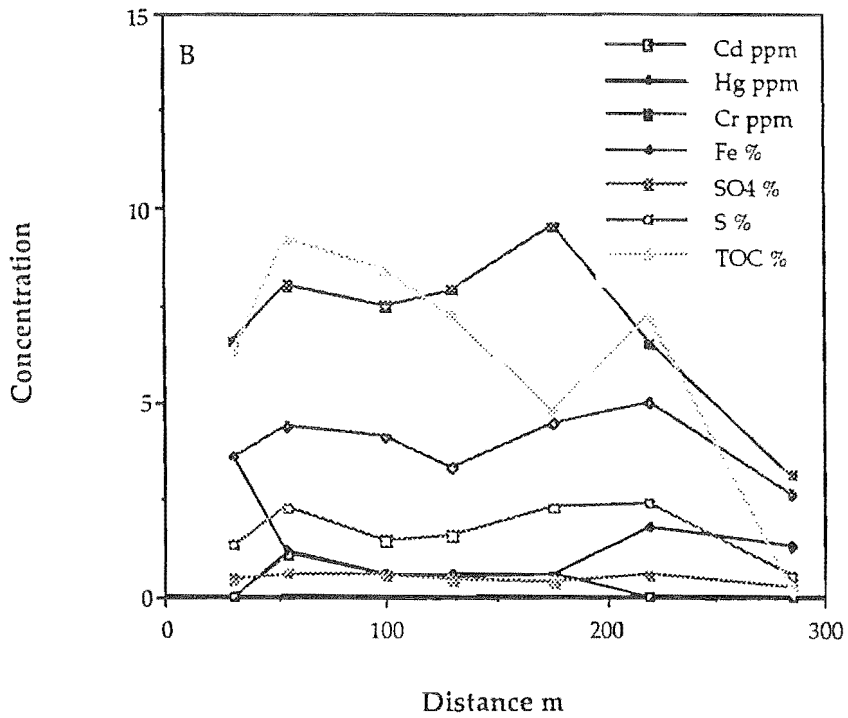


Appendix 4 - 2

Data from transect 1 at a depth of 30cm
for the high concentration metals

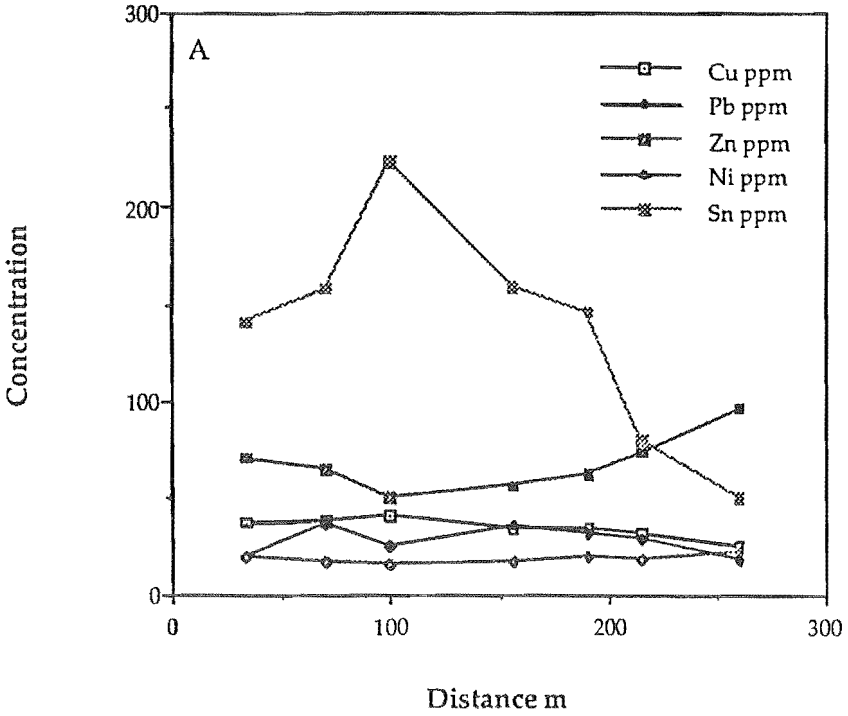


Data from transect 1 at a depth of 30cm
for low concentration metals and anions.

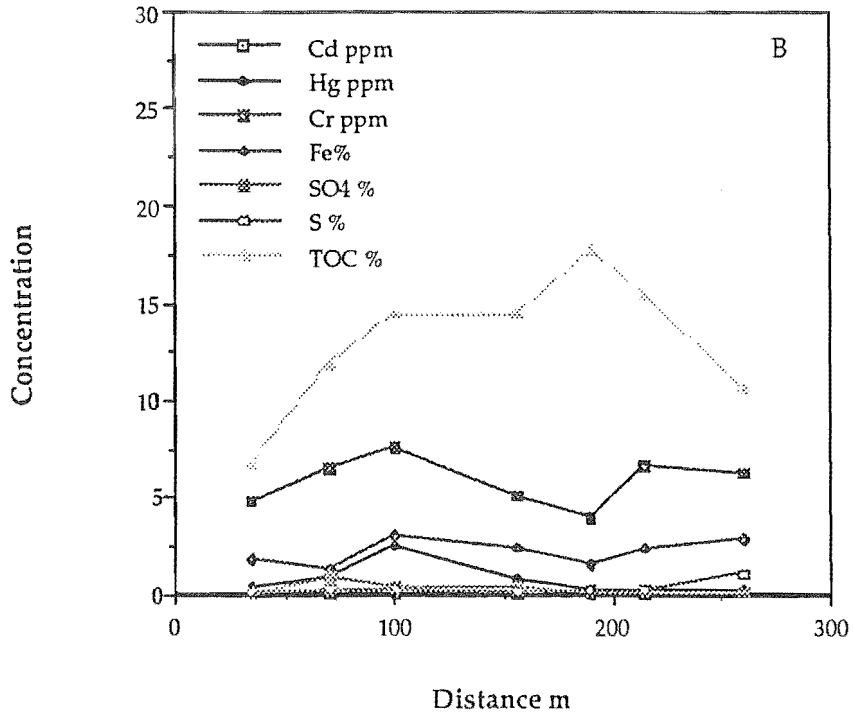


Appendix 4 - 3

Data from transect 2 of the top 5 cm
for high concentration metals

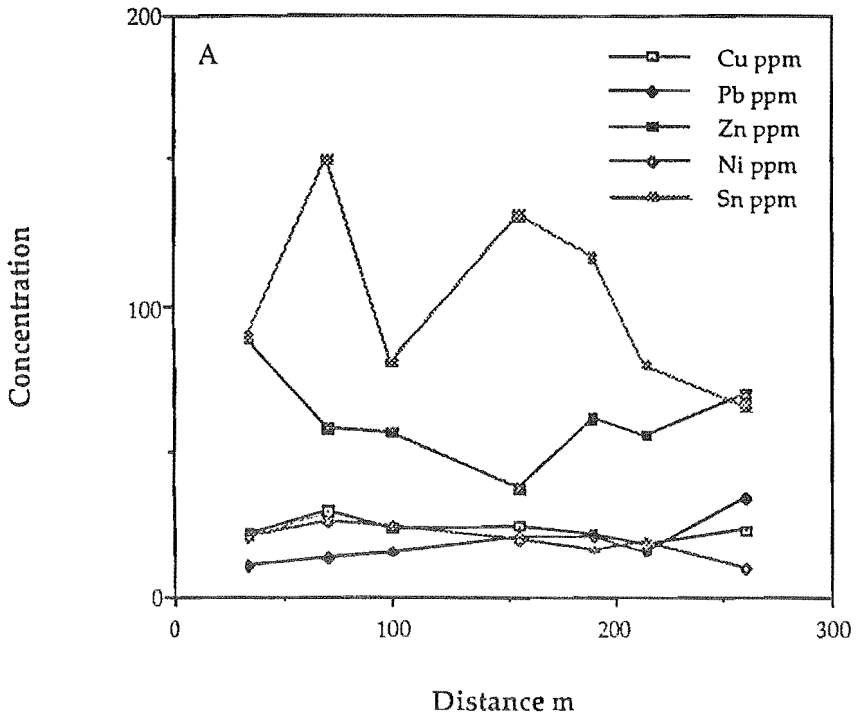


Data from transect 2 for the top 5 cm
for low concentration metals and anions.

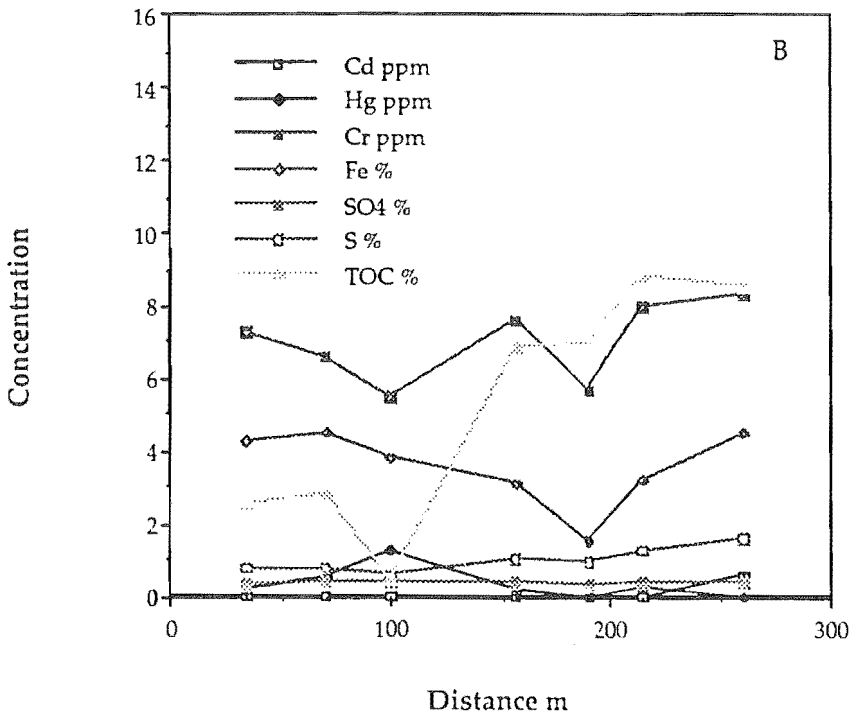


Appendix 4 - 4

Data from transect 2 at a depth of 30cm
for high concentration metals

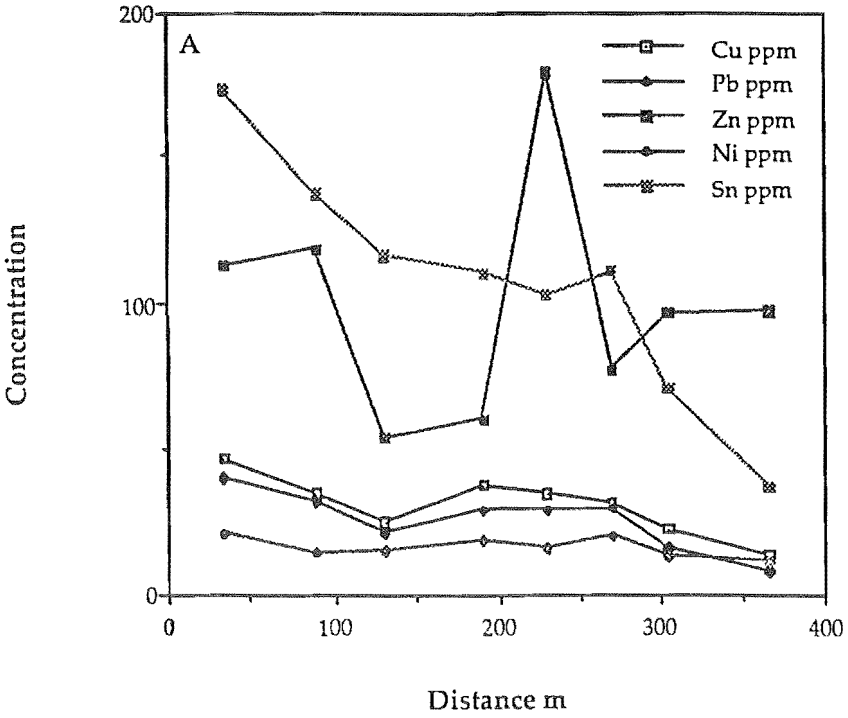


Data from transect 2 at a depth of 30cm
for low concentration metals and anions.

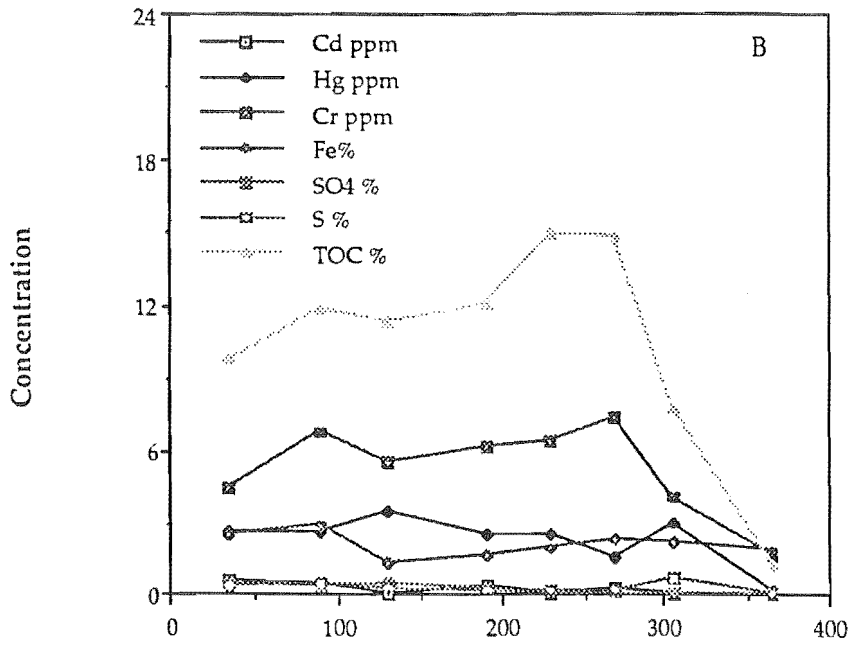


Appendix 4 - 5

Data from transect 3 for the top 5 cm
for high concentration metals

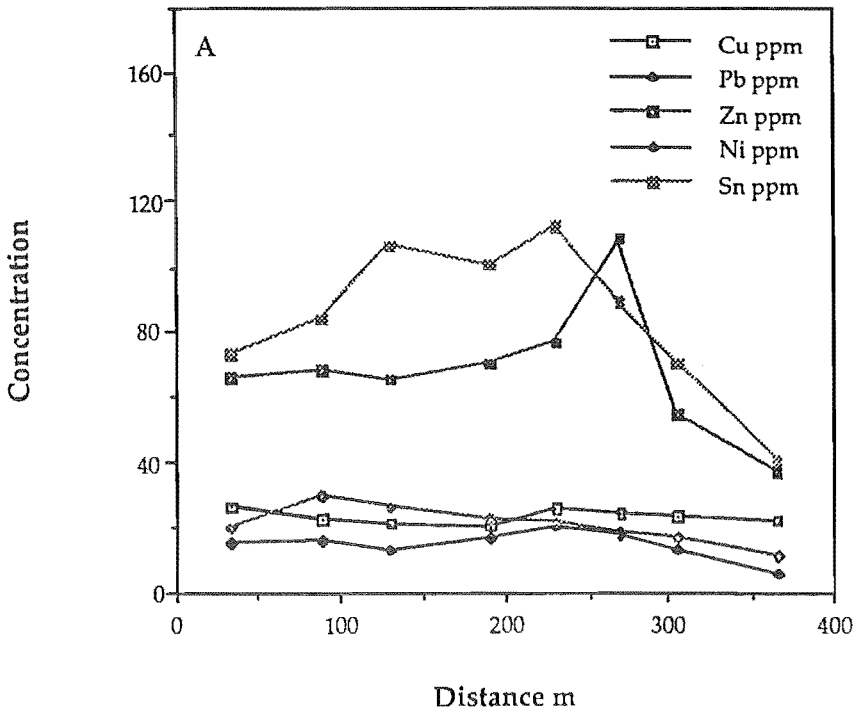


Data from transect 3 for the top 5 cm
for low concentration metals and anions

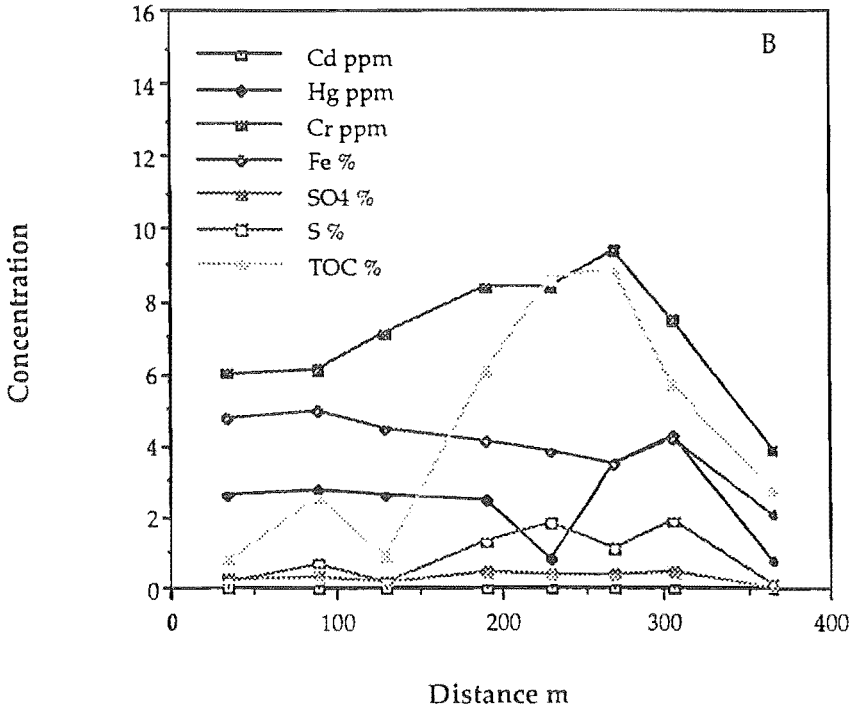


Appendix 4 - 6

Data from transect 3 at a depth of 30cm for high concentration metals

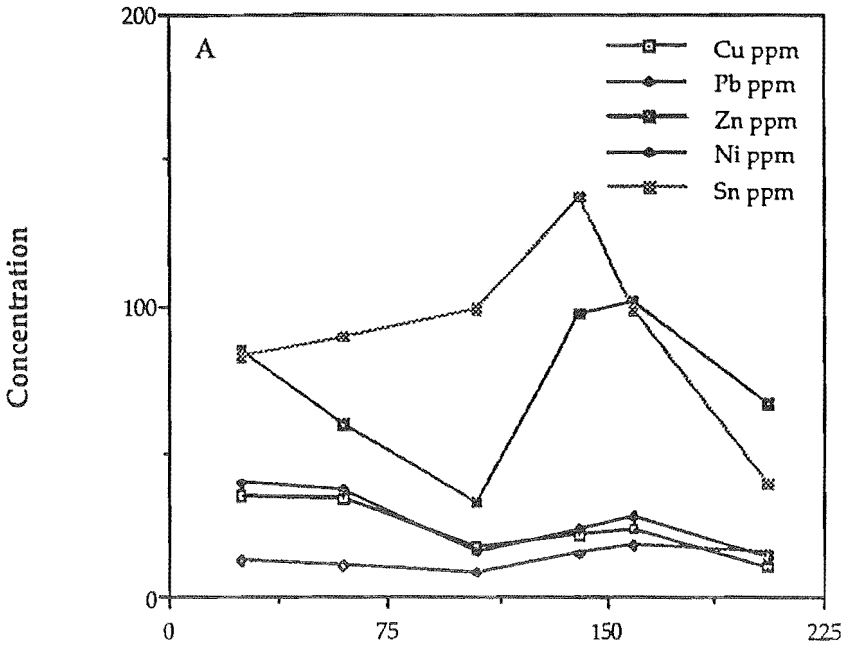


Data from transect 3 at a depth of 30cm for low concentration metals and anions

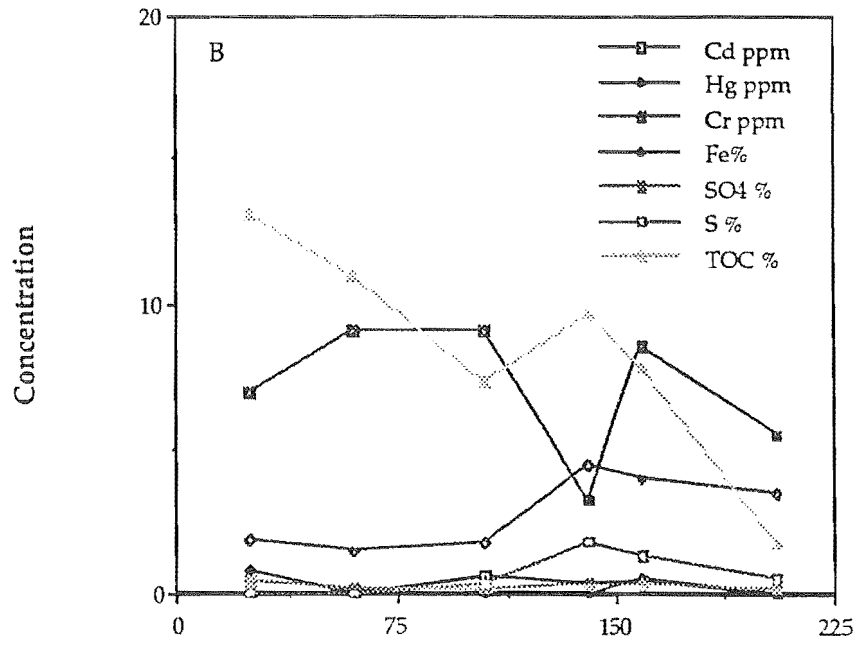


Appendix 4 - 7

Data from transect 4 for the top 5 cm
for high concentration metals

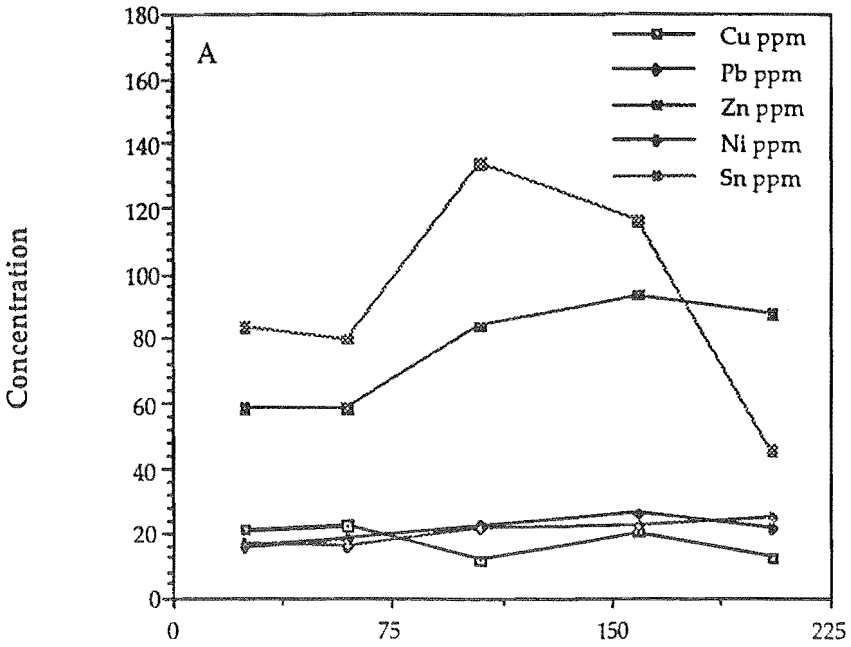


Data from transect 4 for the top 5 cm
for low concentration metals and anions

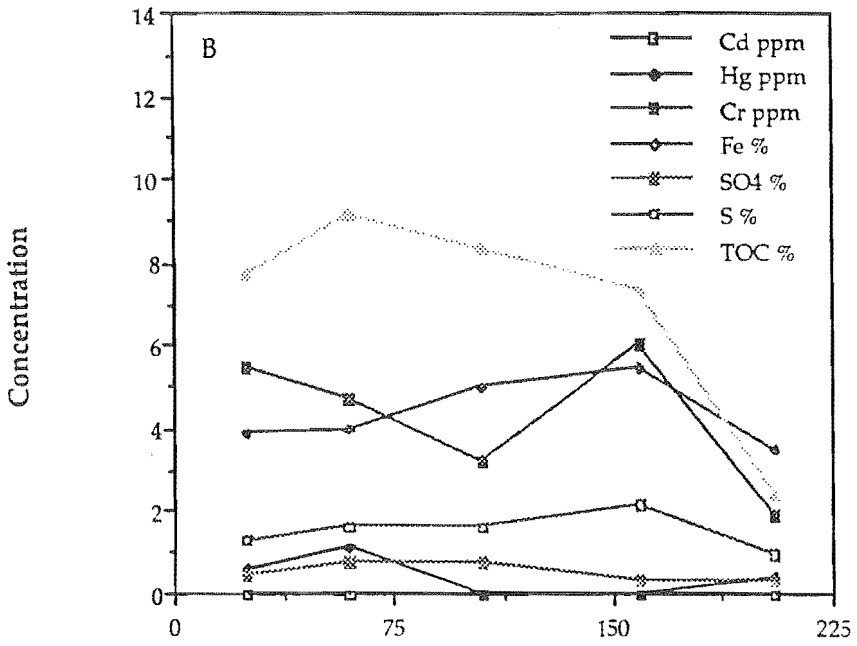


Appendix 4 - 8

Data from transect 4 at a depth of 30cm
for high concentration metals

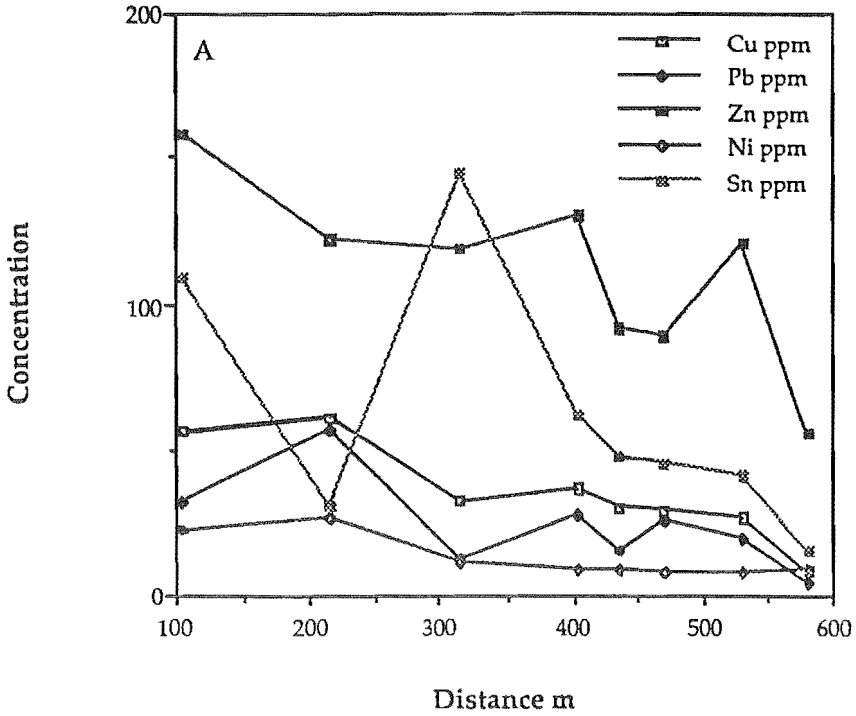


Data from transect 4 at a depth of 30cm
for low concentration metals and anions

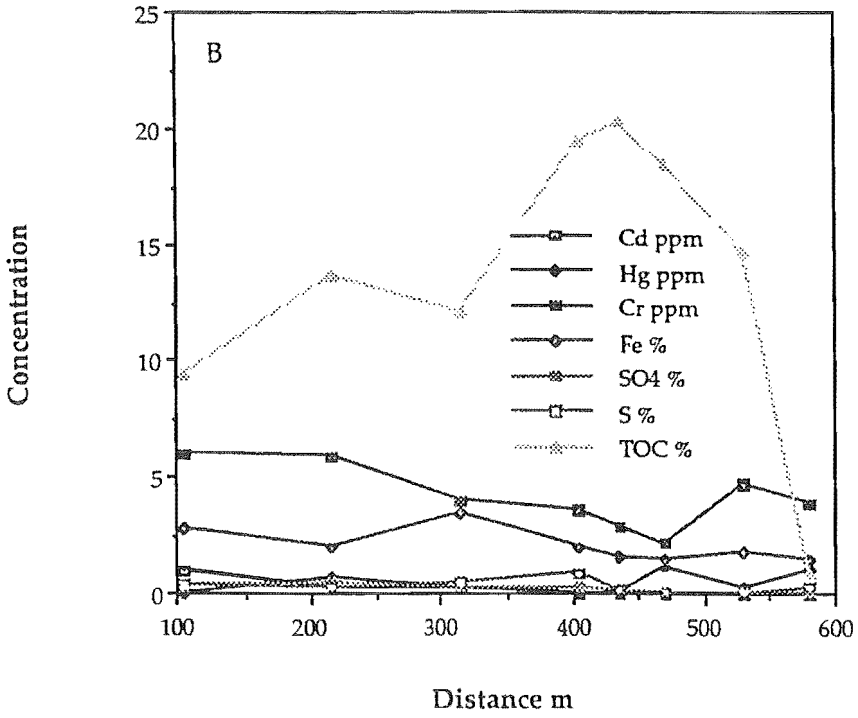


Appendix 4 - 9

Data from transect 5 for the top 5 cm
for high concentration metals

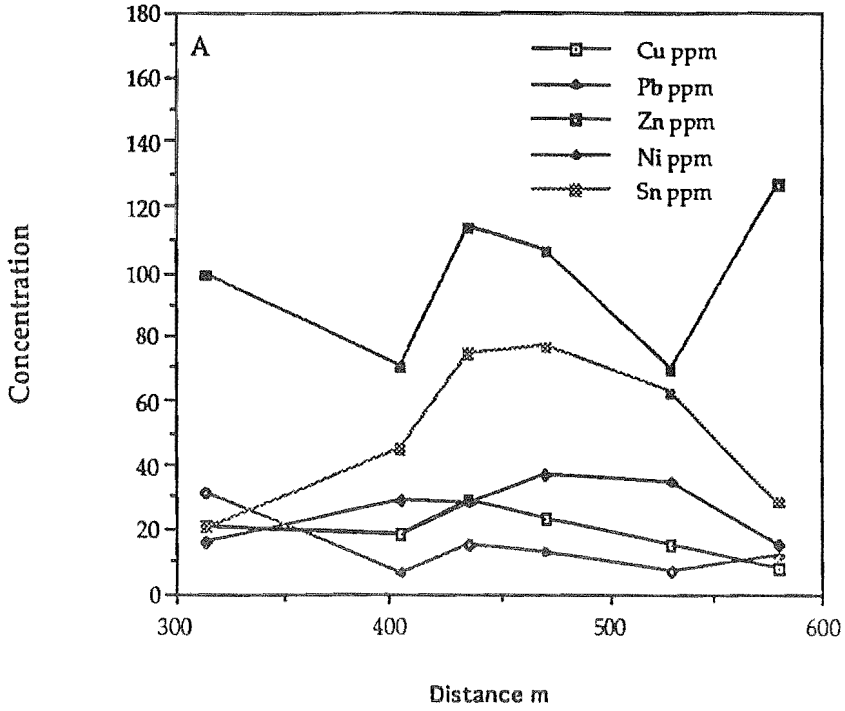


Data from transect 5 for the top 5 cm
for low concentration metals and anions

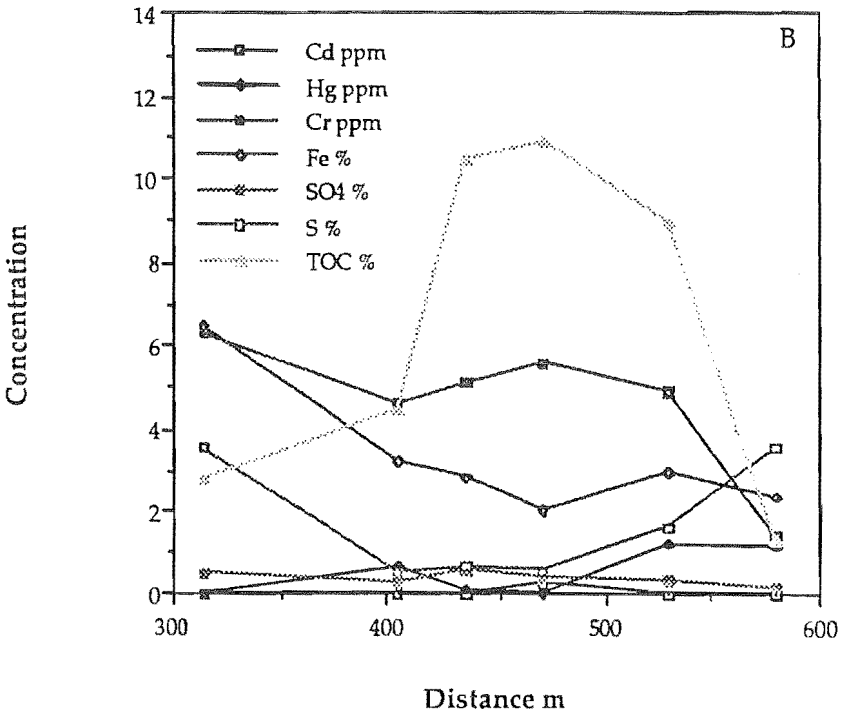


Appendix 4 - 10

Data from transect 5 at a depth of 30cm
for high concentration metals

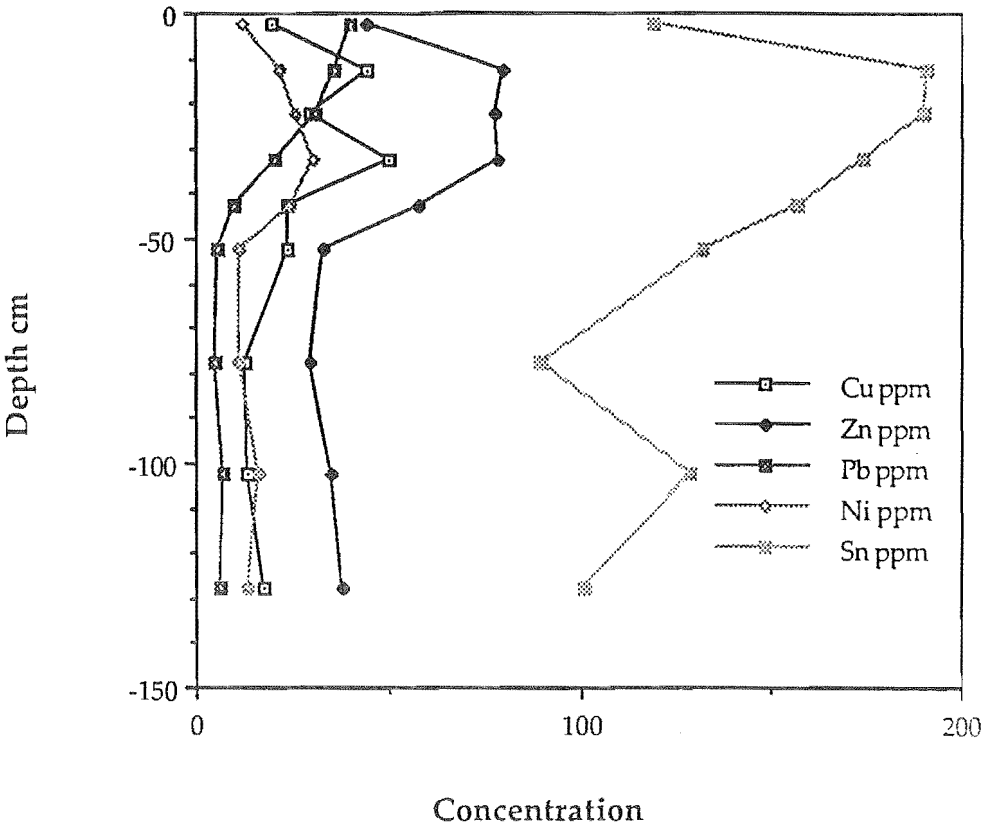


Data from transect 5 at a depth of 30cm
for low concentration metals and anions

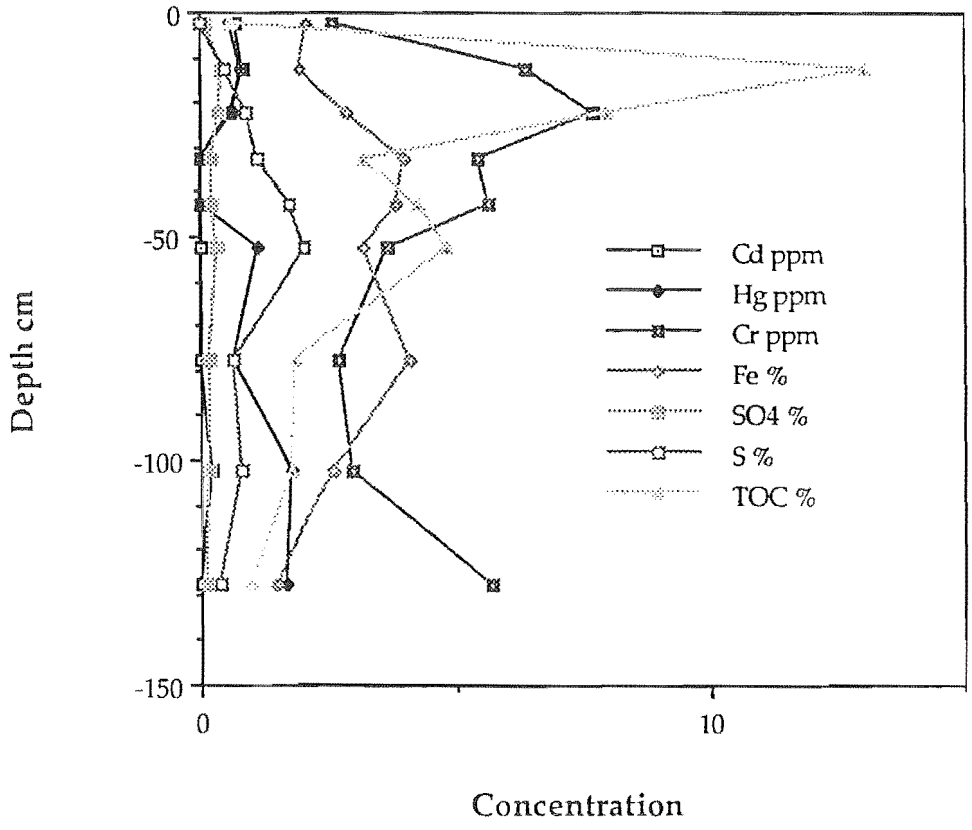


Appendix 4 - 11

Total analysis data from core MCC 001

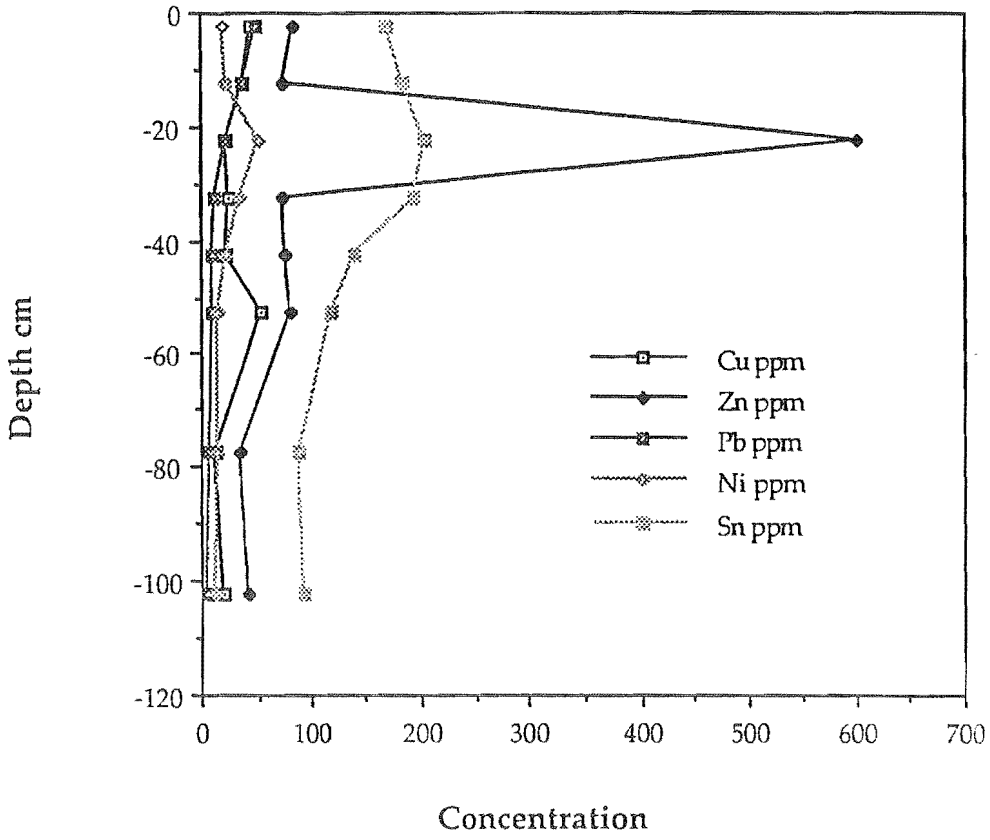


Total analysis data from core MCC 001

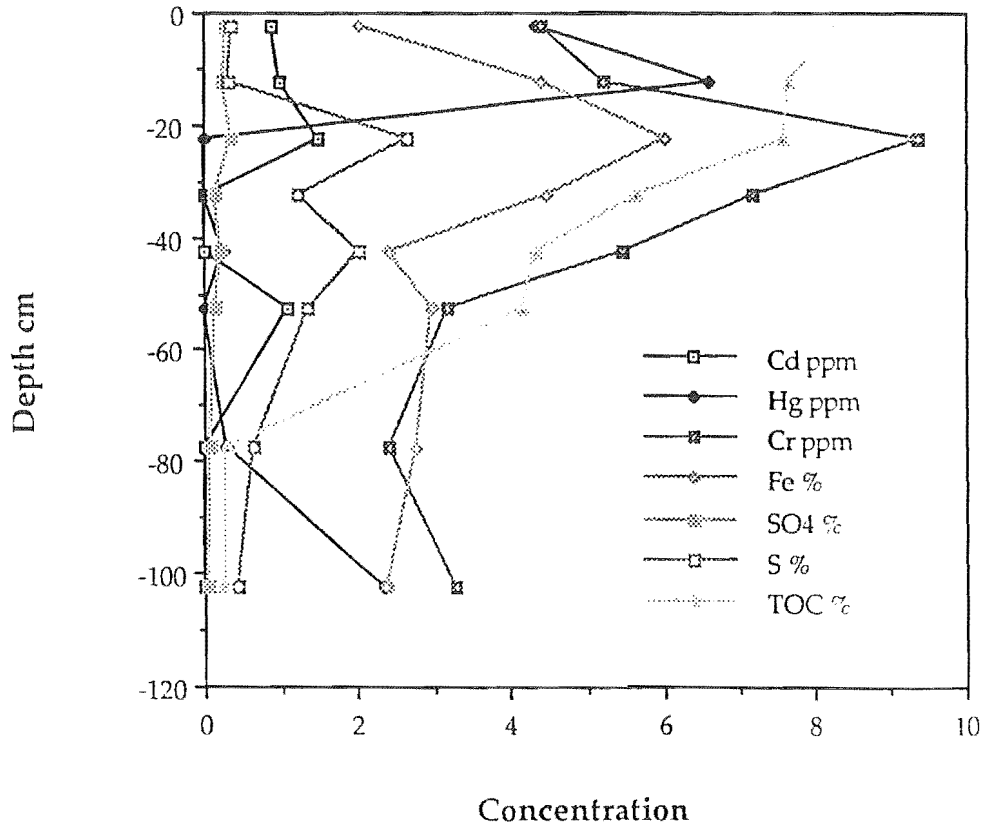


Appendix 4 - 12

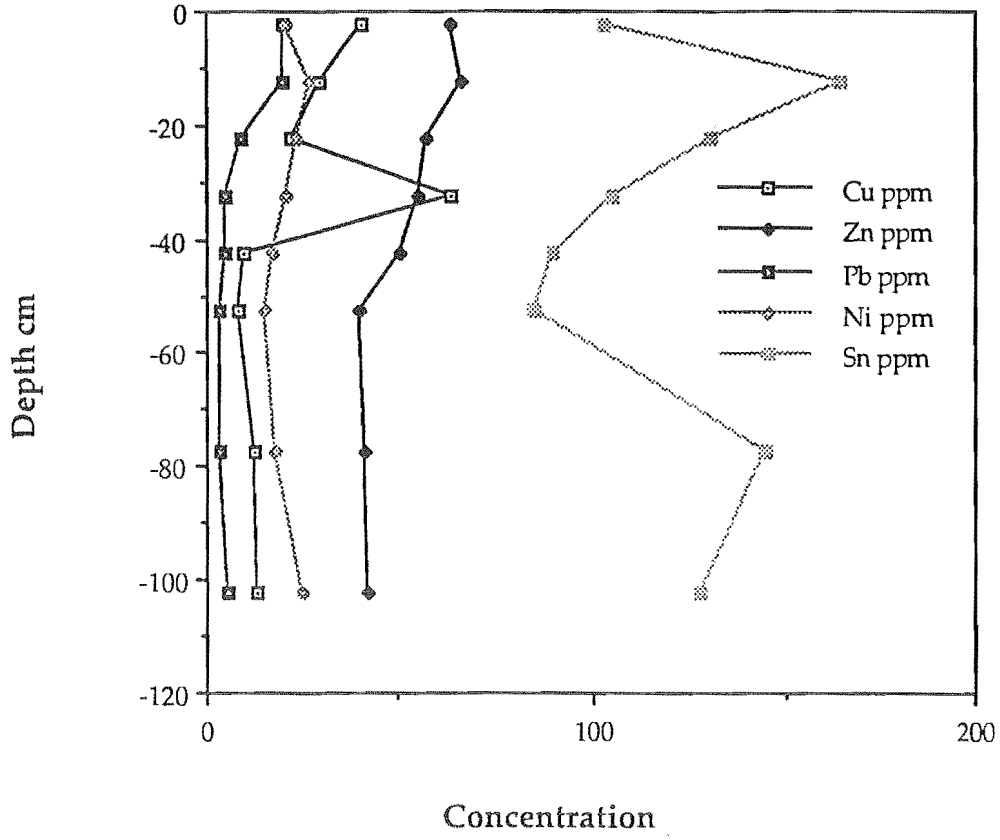
Total analysis data from core MCC 002



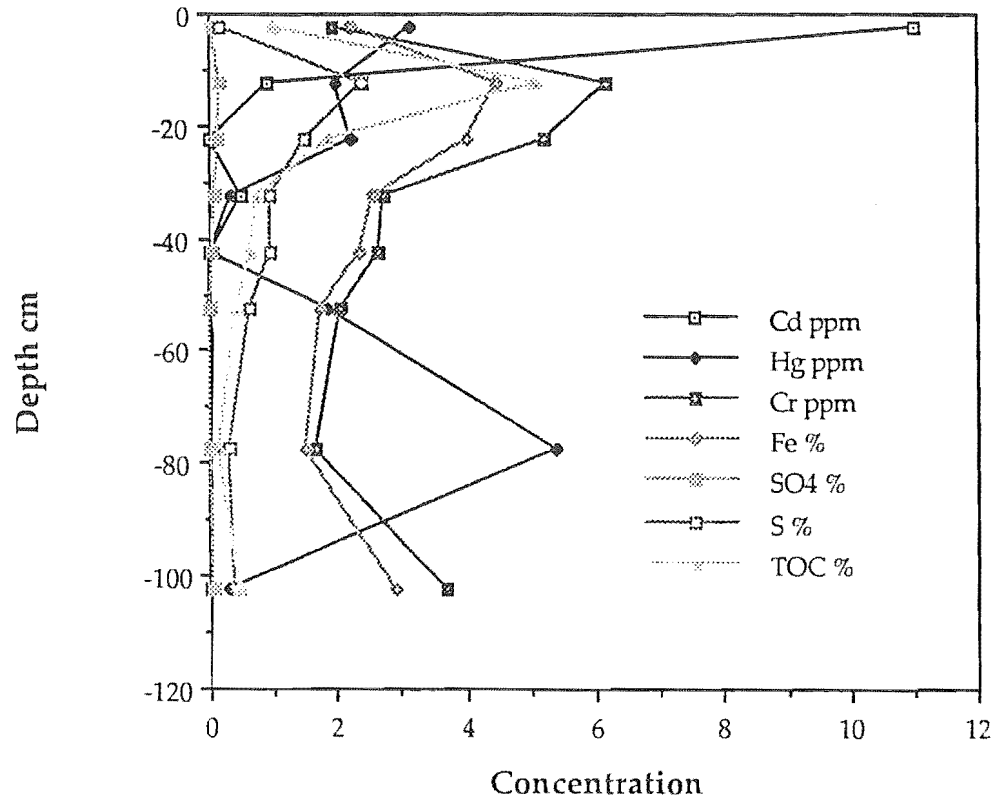
Total analysis data from core MCC 002



Total analysis data from core MCC 003

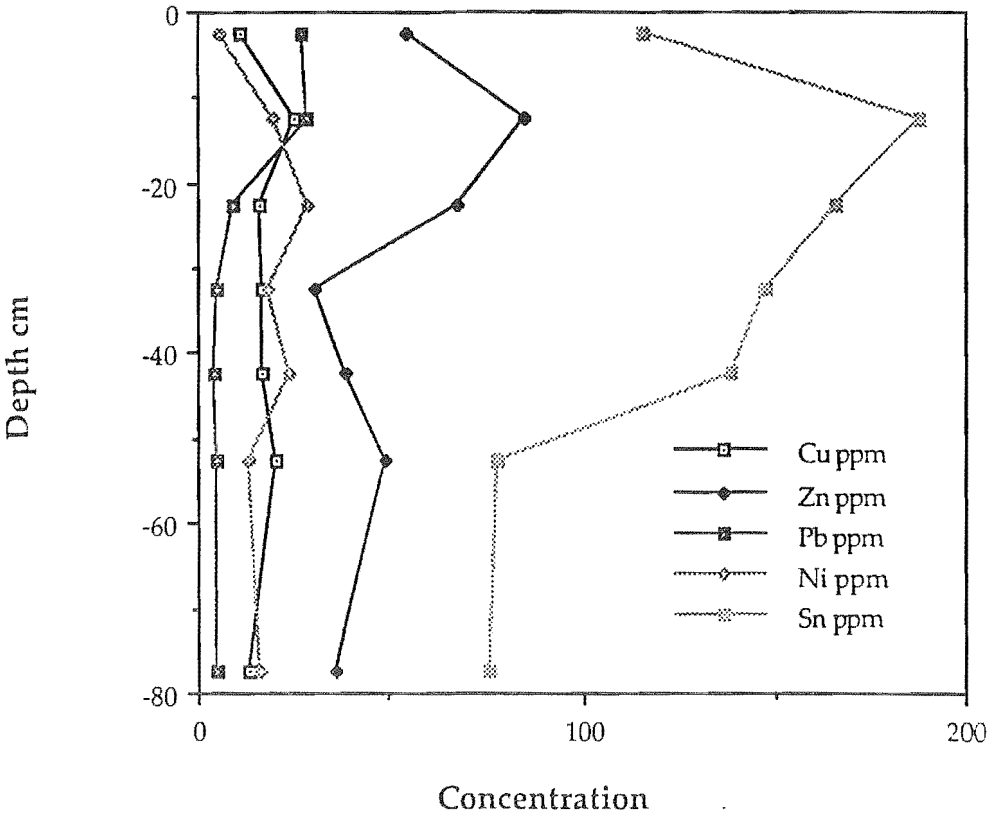


Total analysis data from core MCC 003

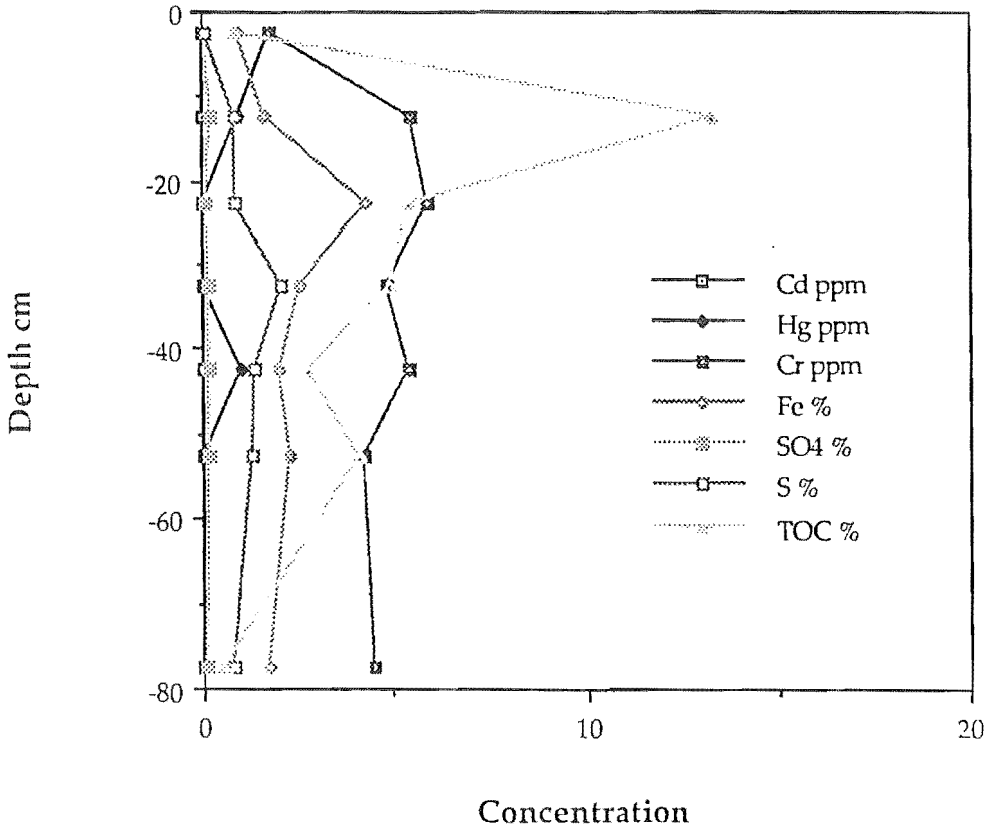


Appendix 4 - 14

Total analysis data from core MCC 004

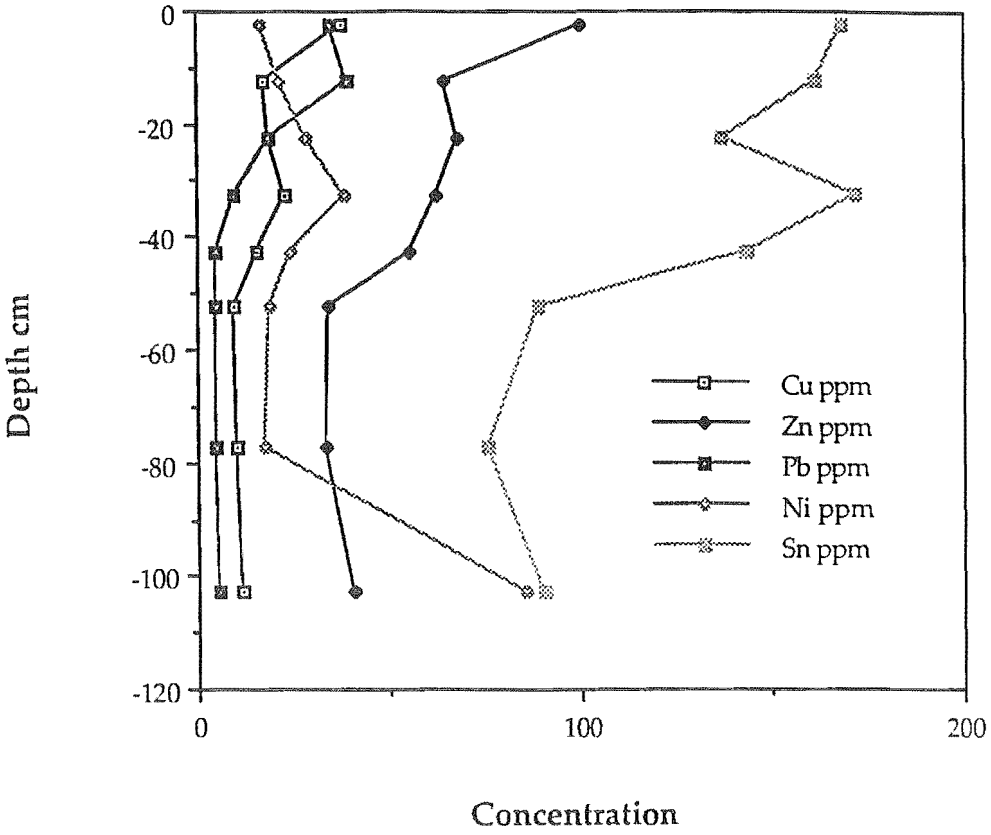


Total analysis data from core MCC 004

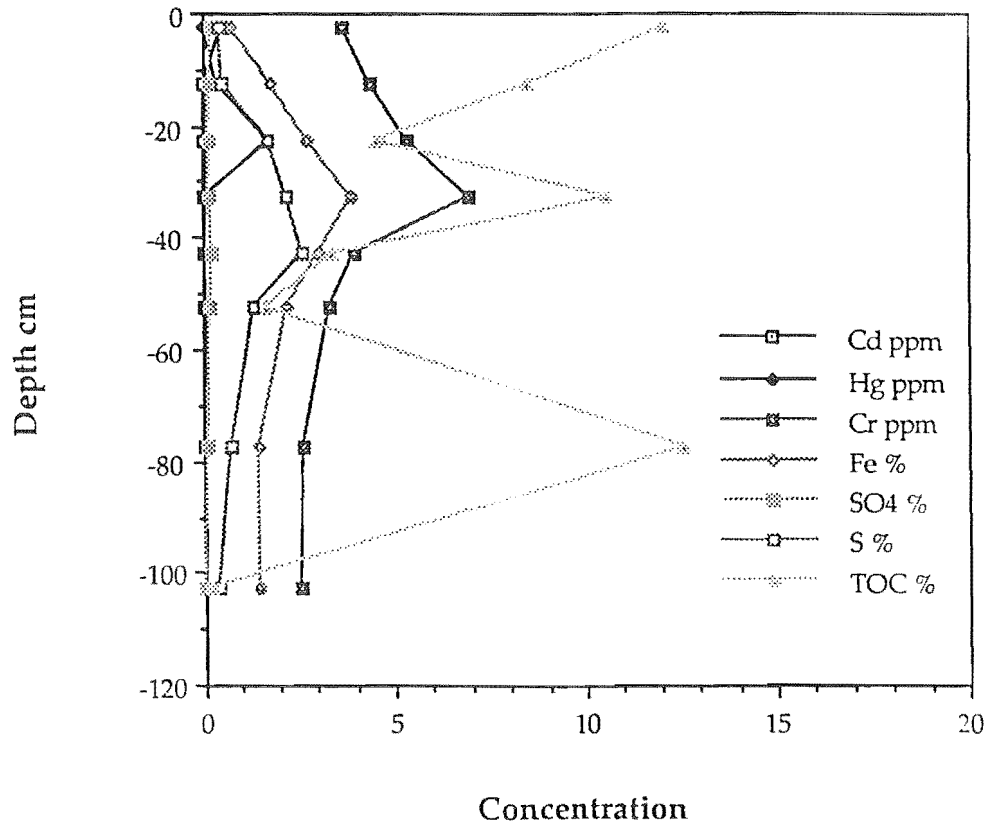


Appendix 4 - 15

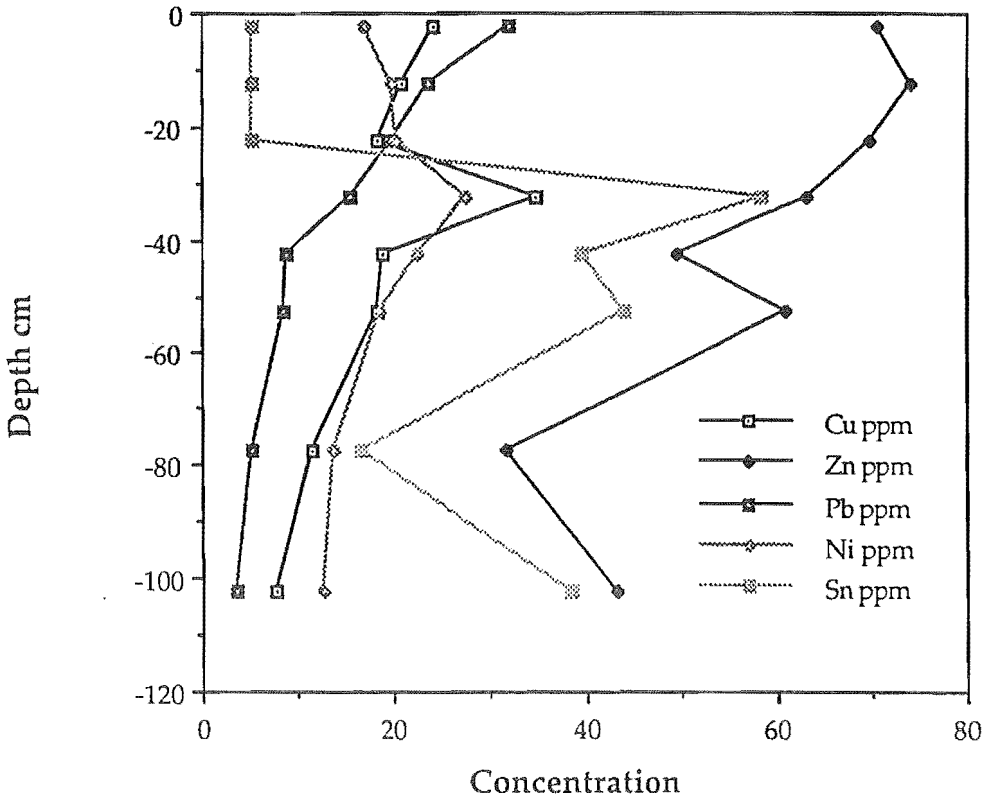
Total analysis data from core MCC 005



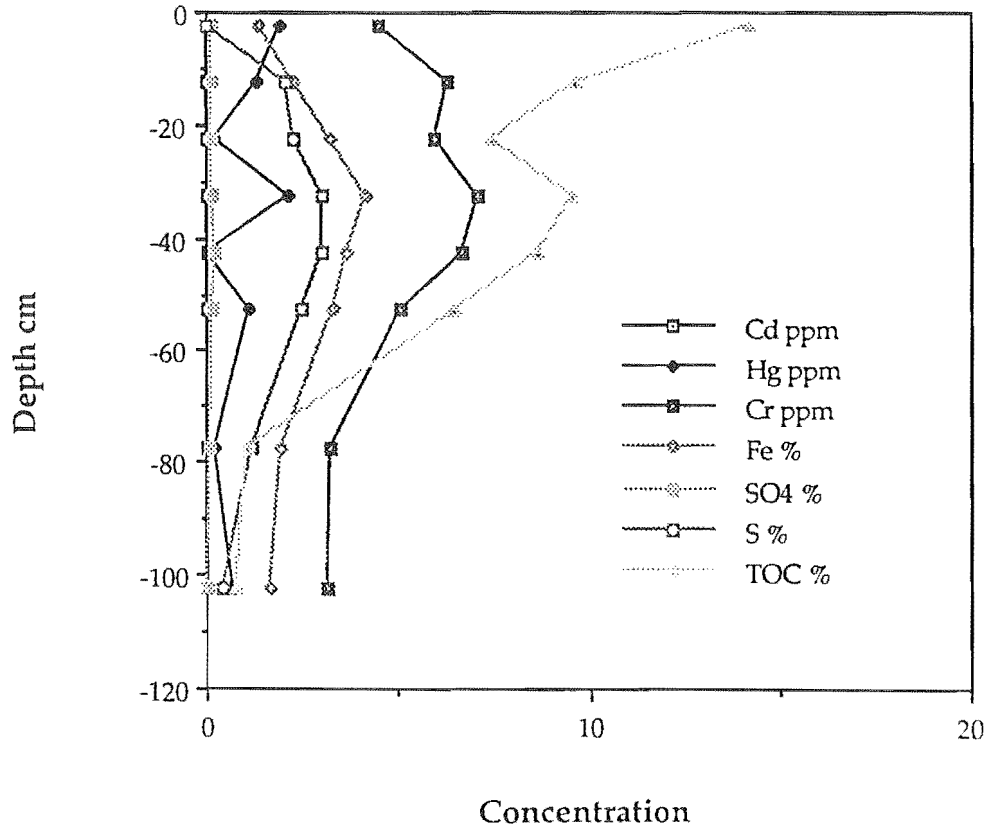
Total analysis data from core MCC 005



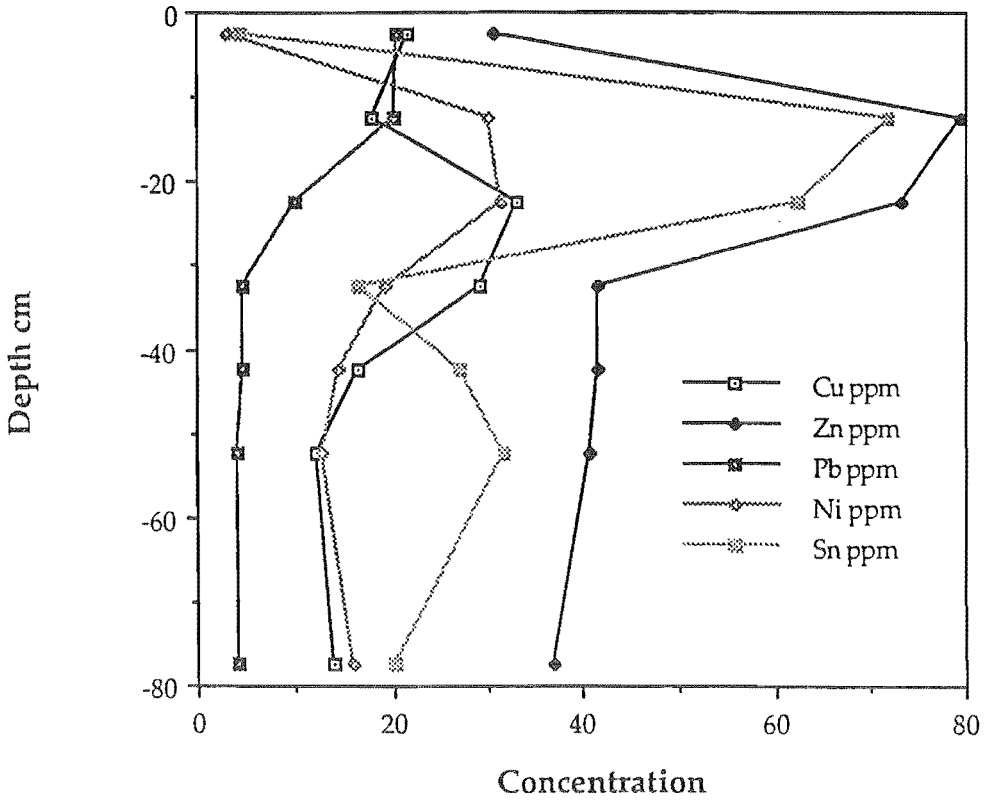
Total analysis data from core MCC 006



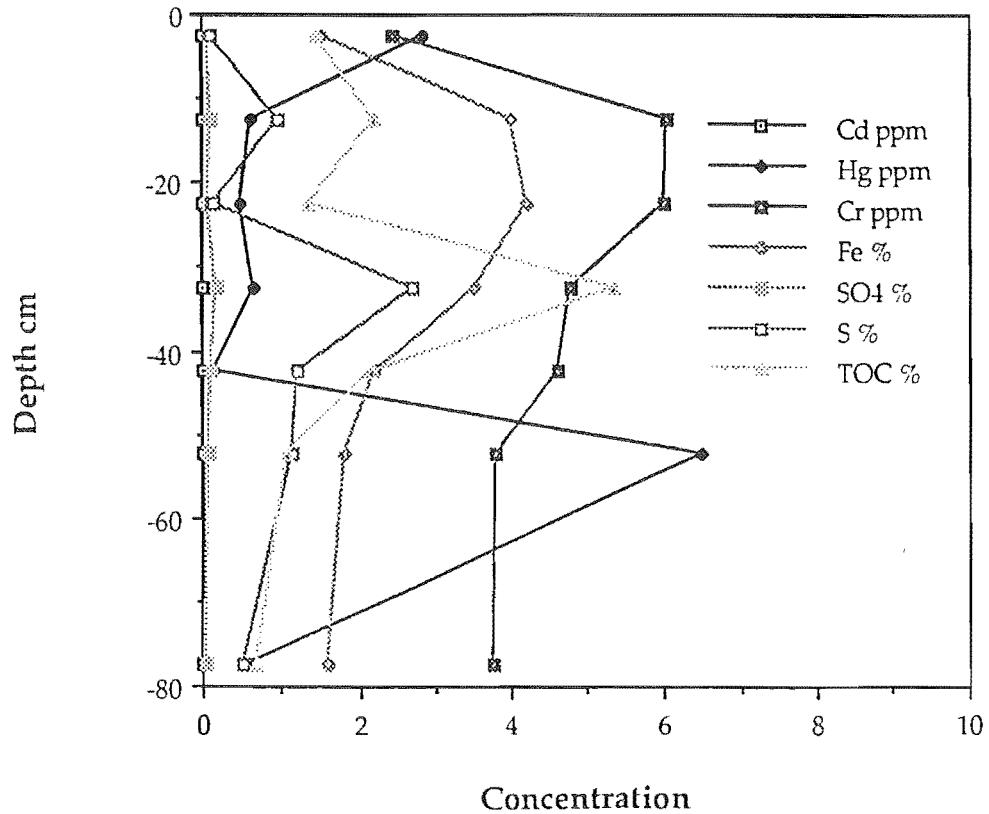
Total analysis data from core MCC 006



Total analysis data from core MCC 7



Total analysis data from core MCC 007



Appendix 4 - 18

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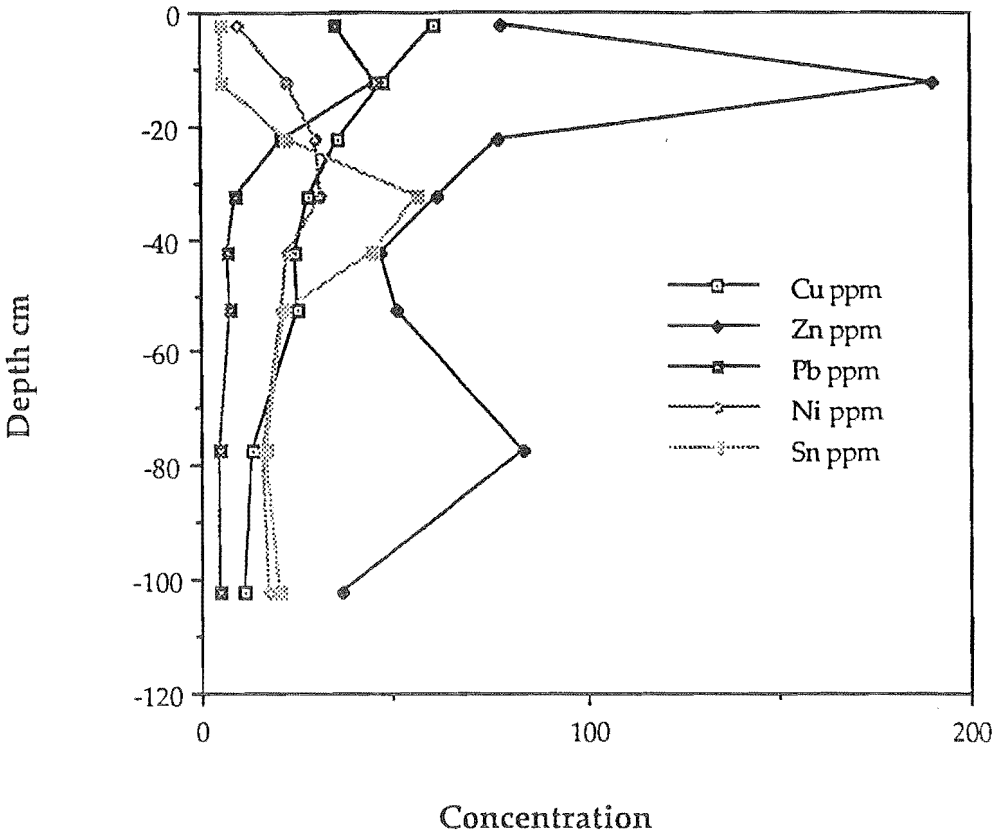

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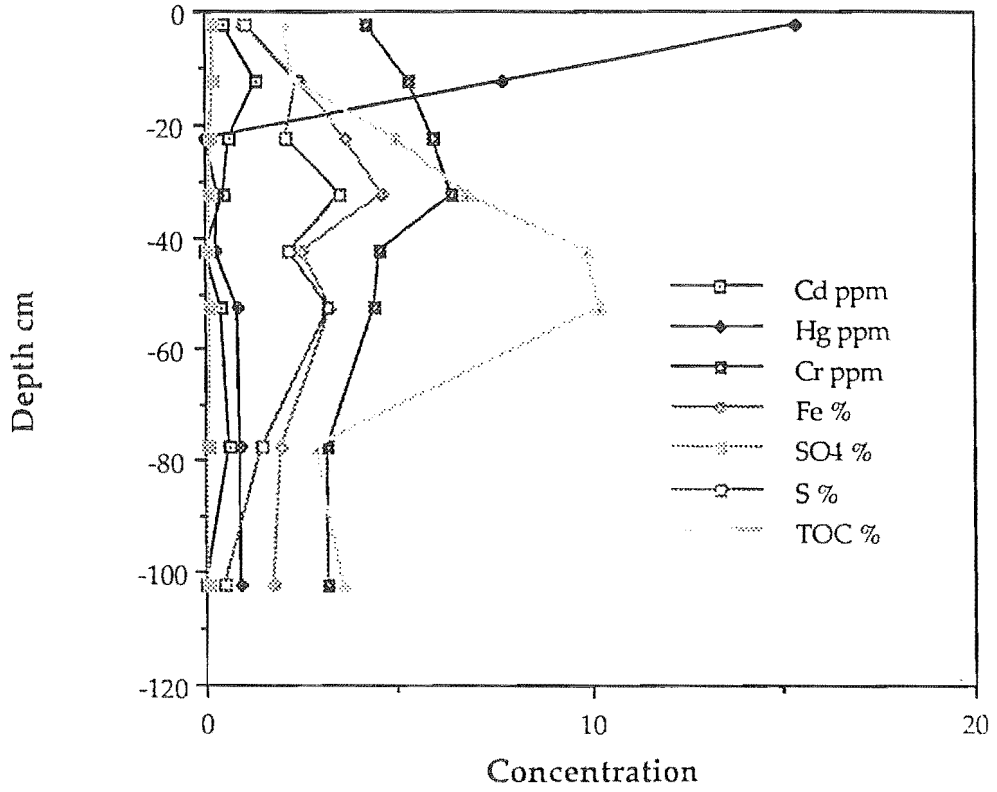

Appendix 4 - 19

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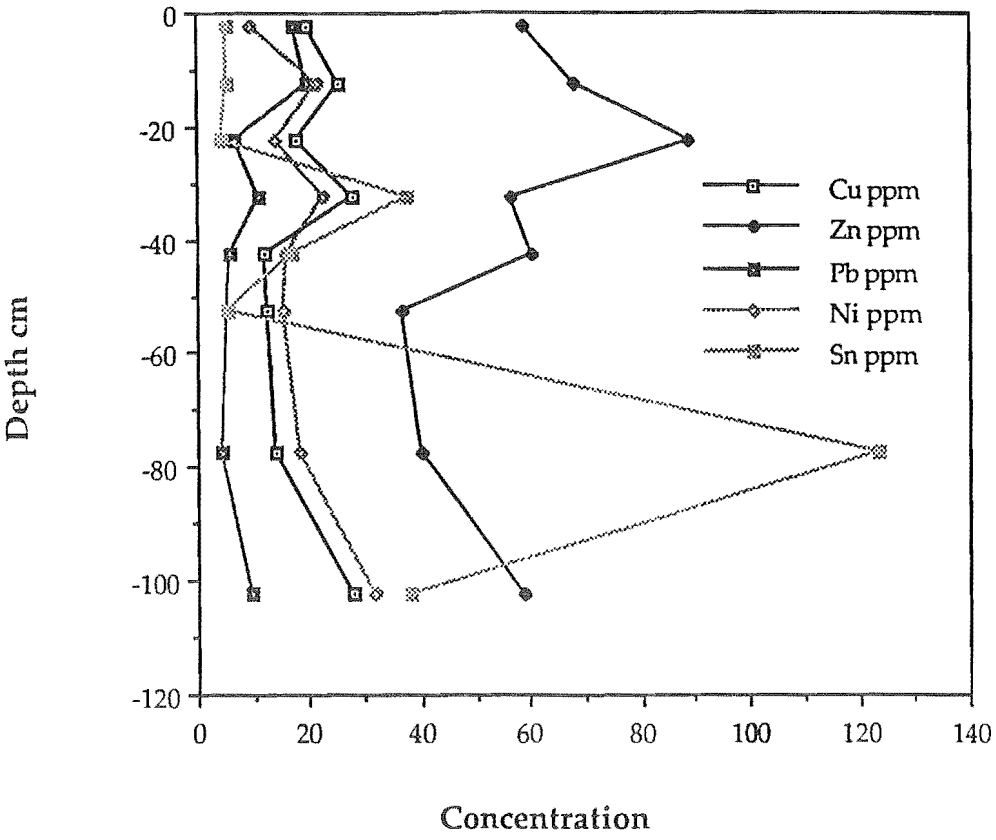

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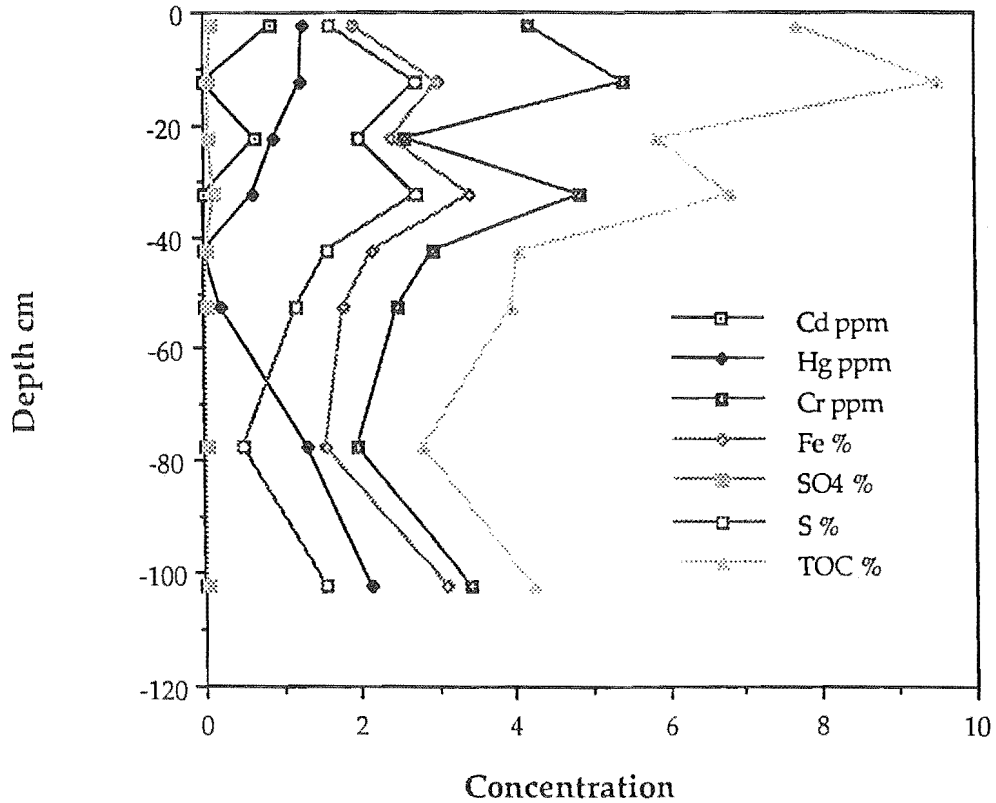

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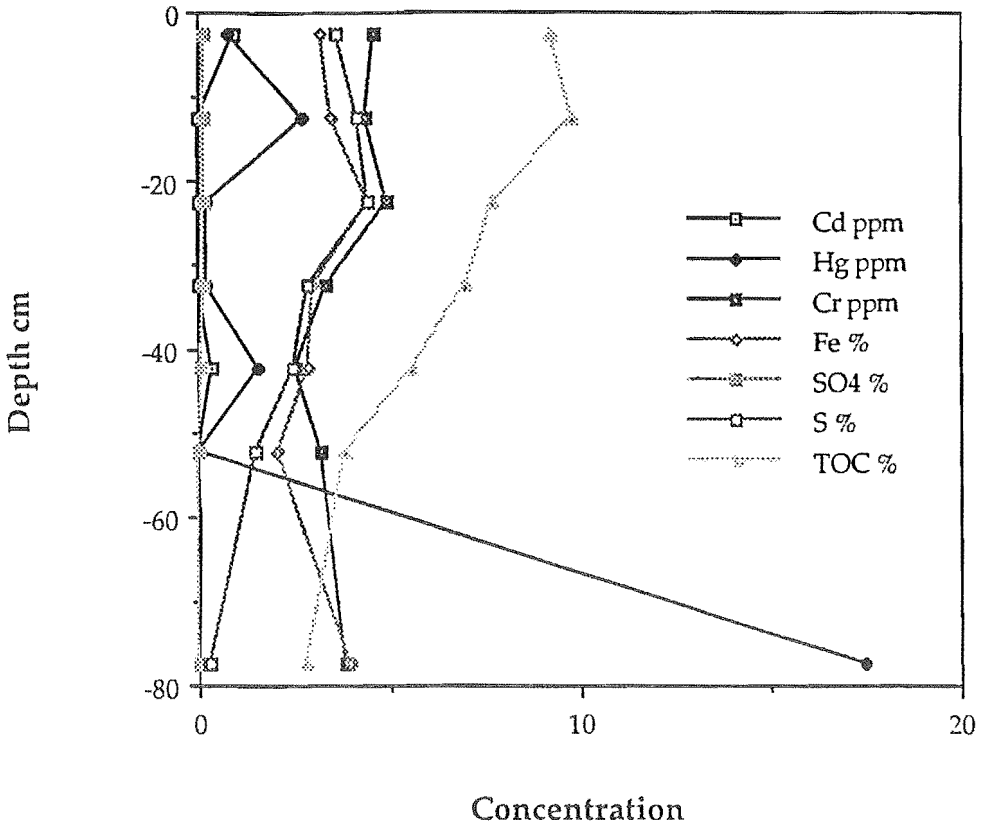

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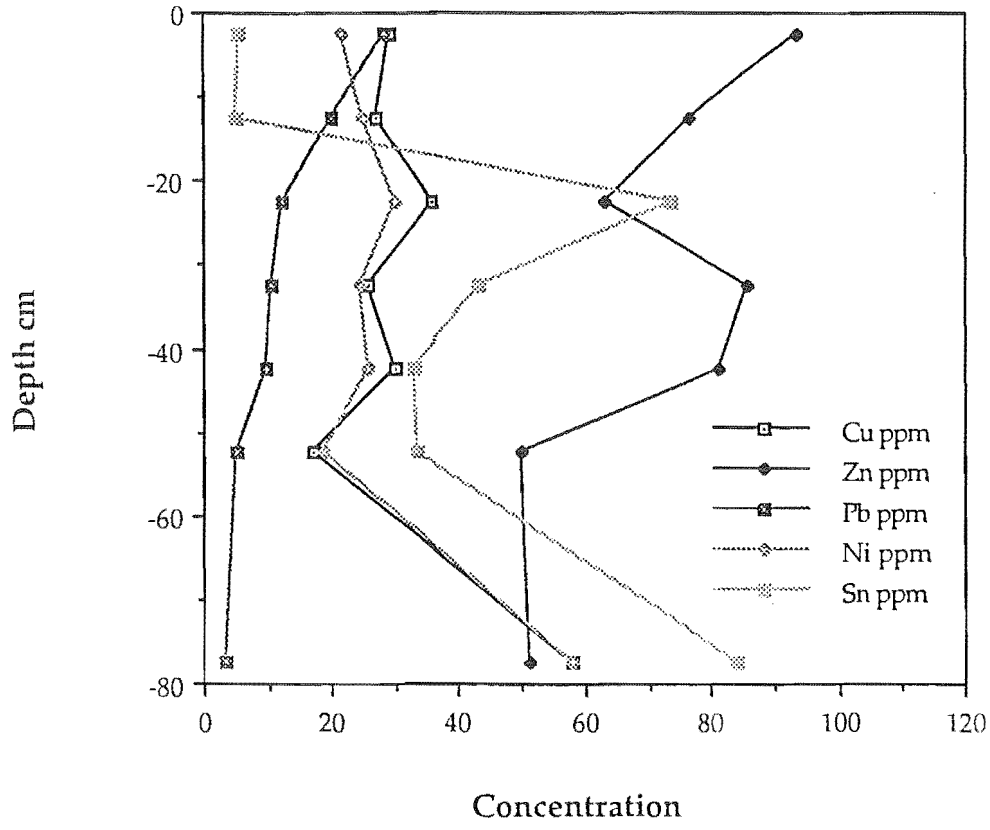

Appendix 4 - 21

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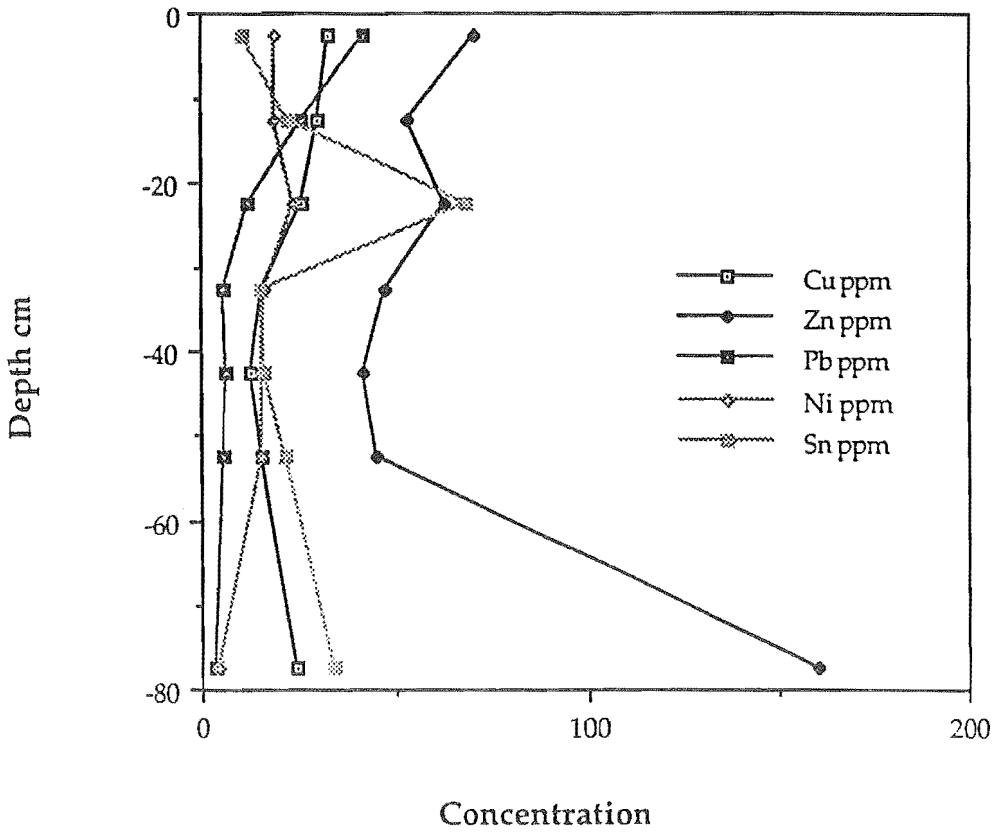

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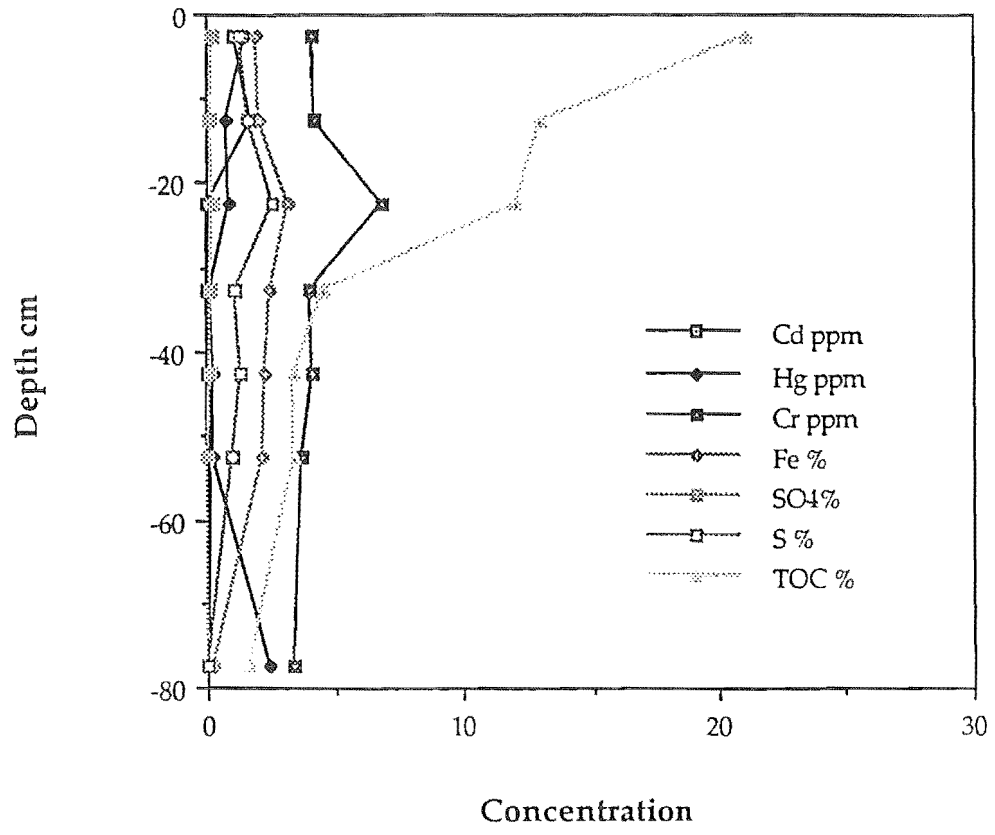

Appendix 4 - 22

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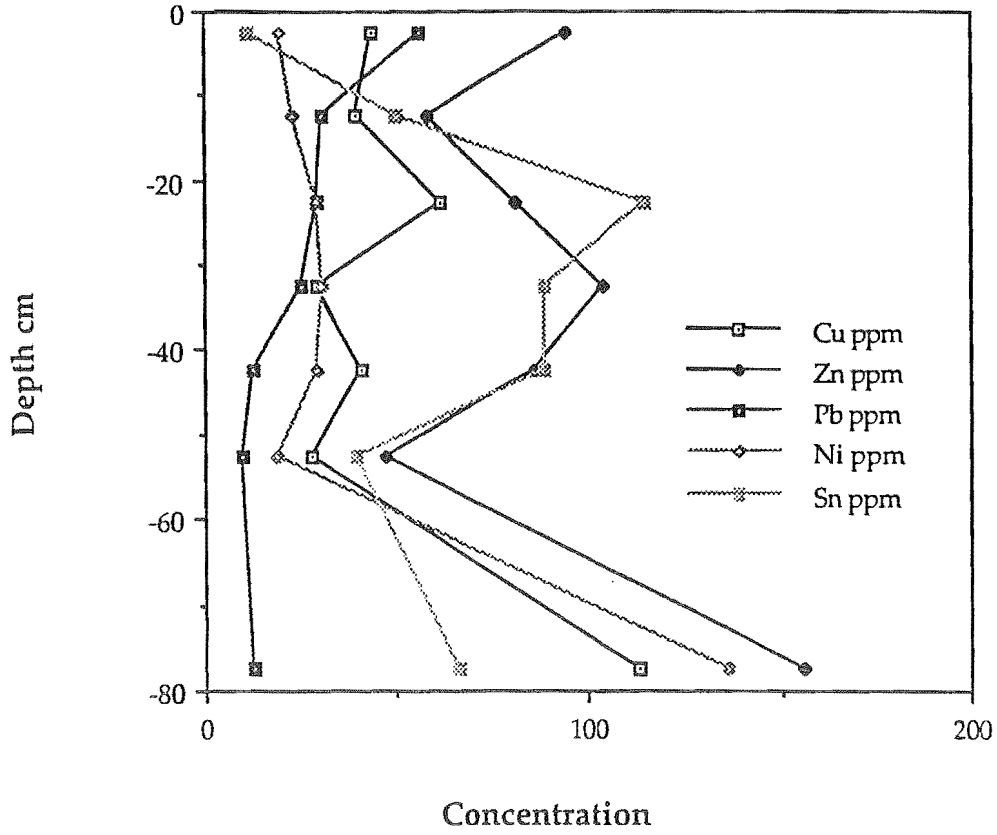

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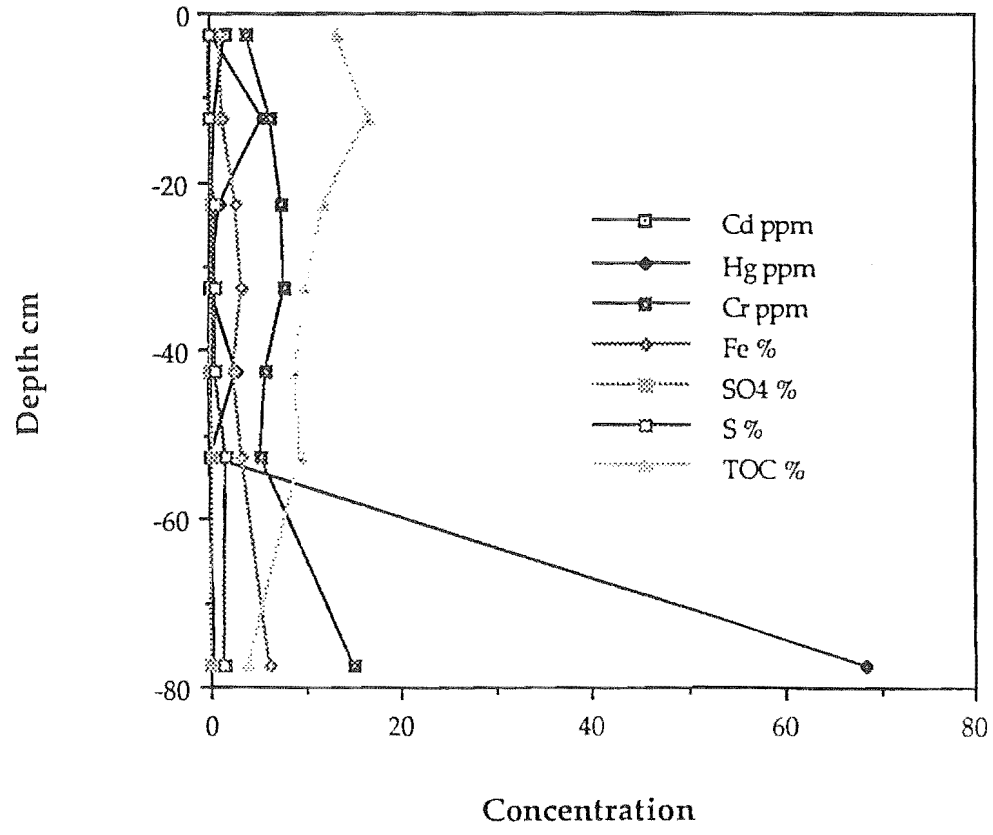

MANGROVE FORESTS AS A BUFFER ZONE BETWEEN ANTHROPOGENICALLY POLLUTED AREAS AND THE SEA

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ABSTRACT

In Australia, recognition of the environmental and economic importance of mangrove ecosystems is reflected in the legislative protection accorded to them by state governments but despite this protection there are many sites where effluent is discharged directly into the mangroves, others where solid wastes are dumped among the mangroves and many where a mangrove forest separates a source of potential pollutants from adjacent marine or estuarine environments. This study of a site near Wynnum tip, Brisbane, is an example of a setting where a mangrove forest separates a source of metallic pollutants from the sea.

Chemical analyses of sediments and mangrove plant tissues show that the mangrove forest and an unvegetated salt flat between the tip face and the forest form an effective barrier against the movement of any metallic tip leachates to Moreton Bay. The mangroves form a baffle which reduces the flow velocity of tidal currents and allows fine grained sediment to accumulate both within and shoreward of the mangrove forest and this in turn provides a suitable habitat for large populations of sulphate reducing bacteria. Direct metal adsorption onto the fine sediment, complexing with organic matter in the sediment and the formation of insoluble metal sulphides, by reaction with bacterially generated sulphide, all contribute to the trapping of metals carried in tip leachates. The fine sulphidic mangrove sediments probably make the major contribution to the biogeochemical trap but direct metal uptake by the mangrove plants also traps substantial quantities of copper, zinc and lead. The extent of metal export from the forest is unclear at this stage but it appears to be quantitatively minor.

Because the reduced sulphidic sediments make such an important contribution to the metal trapping efficiency of the mangrove forest, future land management planning for the area will need to ensure that these sediments are not drained and allowed to oxidise. Oxidisation, which would be a likely result of any draining of the sediment, would not only release many of the presently trapped metals but would probably also create the type of environmental problems typically associated with acid sulphate soil formation.

INTRODUCTION

Mangrove ecosystems can be found in all but the most southerly estuaries and harbours of Australia where they provide nursery or breeding grounds for several commercially important species of marine fauna (e.g., Saenger *et al.*, 1977; Hutchings & Saenger, 1987); many mariculture operations are also undertaken in or near mangrove forests. In Australia, recognition of the primary environmental and economic importance of mangrove ecosystems is reflected in the legislative protection accorded to them by state governments but despite this protection many Australian mangrove forests are polluted by metallic and non-metallic anthropogenic wastes. At some sites effluent is discharged directly into the mangroves, at others a variety of solid wastes are dumped among the mangroves and at others a belt of mangroves separates a source of potential pollutants (such as a refuse tip) from adjacent marine or estuarine environments. Observations in urban mangrove forests in eastern Australia show clearly that although scientific awareness of the importance of these forests as a natural resource has increased, the mangroves are still being used extensively as convenient sites for dumping domestic garbage and siting industrial and local government effluent outfalls (e.g., the sewage outfall ca. 1km north of the tip site, Fig. 1).

The case for the protection of mangrove ecosystems as a buffer between sources of metallic pollutants and nearby aquatic ecosystems has been made previously (Harbison, 1981), but there are surprisingly few papers in the scientific literature on the response of mangrove ecosystems to heavy metals. Although some work on the reaction of mature mangrove plants (Montgomery & Price, 1979; Peterson *et al.*, 1979) and seedlings (Walsh *et al.*, 1979; Thomas & Eong, 1984) to elevated heavy metal loads has been published, most of the work has been carried out overseas and little is known about how Australian mangroves respond to metallic pollutants. To investigate how Australian mangrove ecosystems respond to heavy metals a study was initiated in 1989 by Saenger and McConchie with the following aims:

a) to compare heavy metal concentrations in mangroves growing in areas with low metal loads with those in mangroves from areas where high metal loads are likely,

b) to determine whether common species of mangroves show any tendency toward selective metal accumulation in, or exclusion from, particular parts of the plant,

c) to investigate pathways for metal transfer between mangroves and associated sediment, water, and detritivores, and

d) to assess the value of mangrove forests a buffer between marine environments and sources of metallic pollutants.

In this paper we report on the part of this larger study involving metal distribution in mangrove trees and their substrate sediments at a site near the Wynnum tip-face (Brisbane; Fig. 1). At this site a domestic garbage tip is separated from Moreton Bay by a narrow (ca. 200m wide) belt of mangroves; the mangrove forest and the tip face are separated by a slight depression, roughly 50m wide, which is devoid of any form of macroflora. The unvegetated depression is characterised by highly reducing muds (Fig. 2) which contain an abundance of metallic and non-metallic refuse; assorted metallic and non-metallic rubbish can also be found scattered throughout the mangrove forest. The lack of vegetation in the depression between the tip face and the mangrove forest is probably largely salinity induced and may be compounded by anthropogenic effects. An extensive oil film on the muds and a strong odour of anthropogenic organic chemicals suggest that the lack of vegetation may also be linked to the leachates from the tip. Both tip leachates and the breakdown of metallic refuse dumped in the mangrove forest are potential sources of heavy metals which may be taken up by the trees or adsorbed by the substrate sediment or both.

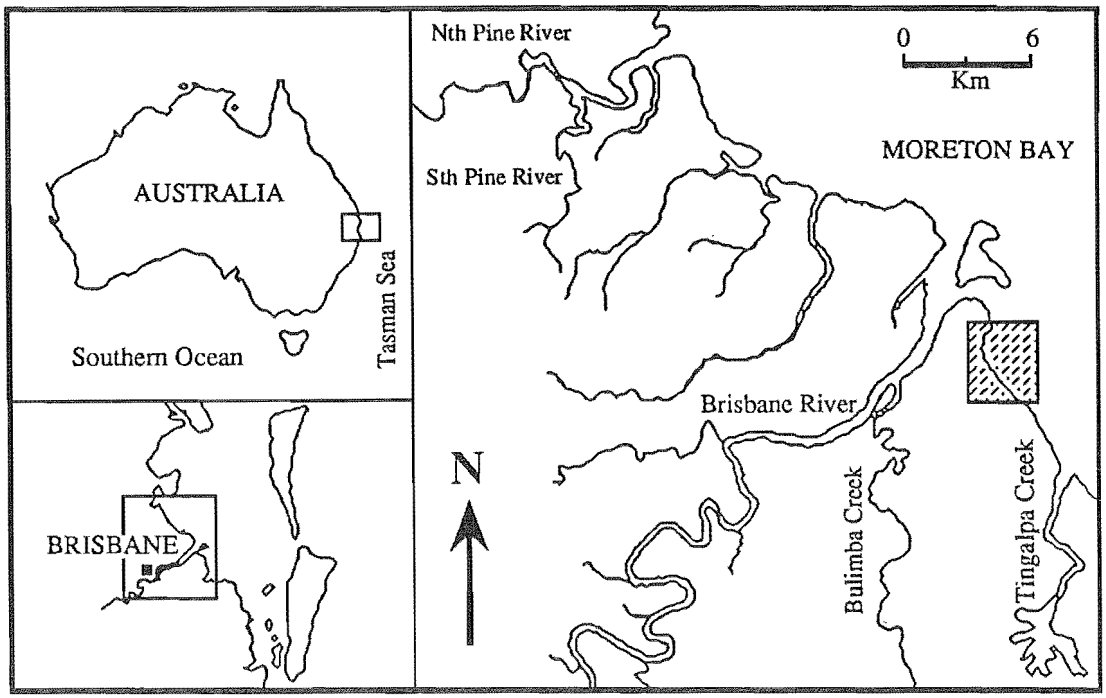

Figure 1: Map showing the location of the Wynnum tip study site (shaded area) to Moreton Bay and Brisbane. The Wynnum sewage outfall is near the northern boundary of the shaded area.

METHODS

Sampling was carried out along two line transects from the tip face across the unvegetated zone and through the mangrove forest to Moreton Bay (Fig. 2). Sediment and mangrove samples were collected along each of the two transects at roughly 50m intervals, commencing at the tip face, except in the unvegetated depression where sediment samples only were obtained.

Sediments were collected as representative samples (Table 1) of the upper 20 cms at each site, dried at 60°C for 48 hrs and digested by boiling in 30% aqua regia for 1 hr; the digests were subsequently analysed by anodic stripping voltammetry using a *Chemtronics* "PDV2000" (see procedures in McConchie *et al.*, 1988) and standard atomic absorption procedures. Redox measurements (using a *Chemtronics* "RSP1000") were recorded for surficial sediment at sites where there was sufficient overlying water to complete the circuit; all Eh measurements are relative to Moreton Bay seawater. More detailed work to determine metal speciation in the sediment and the stratigraphic distribution of metals on the sediment column is currently being completed.

Samples (ca. 100 g) of mangrove wood (several are subdivided into old and young wood), bark, seedlings and leaves (old and young) were collected from trees growing within a 5m radius of the sediment sample site; mangrove leaf litter was collected where suitable accumulations were available. Most samples were of *Avicennia marina* (Table 2) but where suitable trees were available near the site, *Rizophora stylosa, Ceriops tagal* and *Aegiceras corniculatum* trees were sampled (Table 3). Mangrove tissue samples were dried at 60°C for 48 hrs, digested by boiling in concentrated HNO_3 and 120 vol. H_2O_2 until no solid particles remained and made up to 50 mL with analytical grade water; the digests were subsequently analysed using the same procedures as employed for the sediment samples.

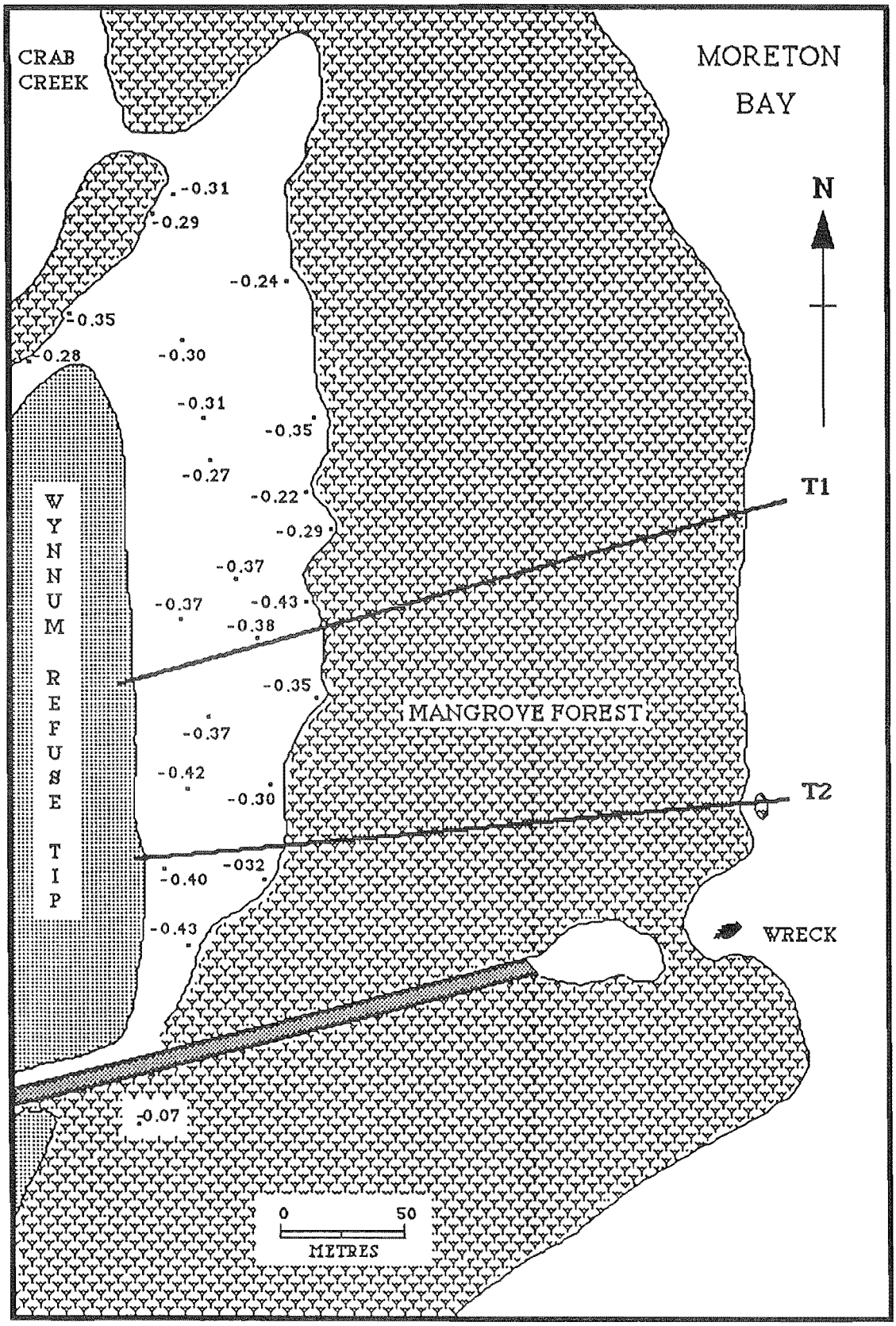

Figure 2: Map of the Wynnum tip site showing sampling transects are labelled T1 and T2. Numbers in the unvegetated zone are Eh values in volts (relative to Moreton Bay sea water) for surficial sediment.

RESULTS

The analytical data for sediment samples are summarised in Table 1 and depicted graphically in Figs. 3 - 6. These data show a clear trend toward an increase in metal concentration near the tip face but it is noted that even the highest concentrations recorded are not exceptionally high relative to similar fine grained reducing sediments elsewhere (e.g., Förstner & Wittman, 1981; Förstner, 1989). It is also clear from the figures that the metal concentration decreases rapidly away from the tip face with the presence of the tip causing no statistically significant rise in metal concentrations on the seaward side of the mangrove forest. Almost all the samples with noticeably elevated metal loads are from in, or very close to, the unvegetated zone between the tip and the mangroves where the sediment Eh is particularly low and it is likely that the reducing muds in this area are trapping any metals which do leach from the tip.

TABLE 1

Analytical data for sediment samples

Transect, distance from tip face (m)	Copper (mg/kg)	Lead (mg/kg)	Zinc (mg/kg)	Cadmium (mg/kg)
1,20	210.69	38.74	339.22	0.29
1,50	184.07	29.29	293.25	0.14
1,70	134.18	26.91	210.55	0.15
1,120	69.58	13.98	117.79	0.08
1,170	31.00	9.69	87.37	0.02
1,220	34.22	12.19	96.86	0.04
1,270	35.63	13.02	85.18	0.03
1,320	31.73	8.43	62.63	≤0.01
1,360	32.25	7.98	48.81	≤0.01
2,80	199.82	28.75	283.40	0.51
2,120	99.88	21.40	176.56	0.19
2,200	79.72	20.17	108.53	0.06
2,280	39.33	15.83	53.00	0.03
2,360	25.03	10.06	46.42	≤0.01

The analytical data for mangrove tissue samples are summarised in Table 2 (for samples of *Avicennia marina*) and Table 3 (for samples of other mangrove species). Plots of zinc and copper concentrations for each type of mangrove tissue show a similar regular decrease in metal concentration with increasing distance from the tip face to those shown in Figs. 3 - 6 for the sediment but the magnitude of the change is less. For lead there is no regular increase in metal concentration toward the tip face except in the wood and the young leaves; no part of the mangrove trees shows a consistent increase in cadmium concentration toward the tip face. Evidently, some metal concentrations in some parts of the plants are influenced by the availability of metals in tip leachates but the degree of influence varies between metals and between different parts of the plant.

As a check on how representative samples of parts of mangrove trees are, in relation to the metal concentration in those parts of the whole tree, multiple samples were obtained from a tree at the seaward end of transect 1 to evaluate the standard error for each metal in each part of the plant. The data obtained from this tree showed that the standard error for copper ranged from 6.1% in the young leaves to 11.5% in the bark, for lead ranged from 11.7% in the bark to 27% in the wood and for zinc ranged from 6.7% in the bark to 12.5% in the old leaves; a standard error could not be determined for cadmium because concentrations were too close to the lower limit of detection. Overall, the standard error data suggest that, with the possible

exception of lead, the metal concentrations in single samples (roughly 100 g) of each tissue type obtained from part of a mangrove tree are representative of the metal concentrations in that tissue type for the whole tree to within less than ± 15%.

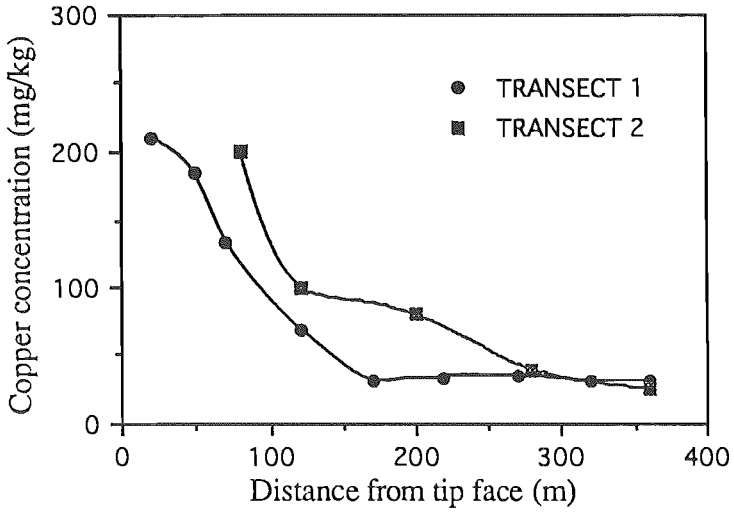

Figure 3: Plot showing the variation in copper concentration in sediment samples as a function of distance from the tip face.

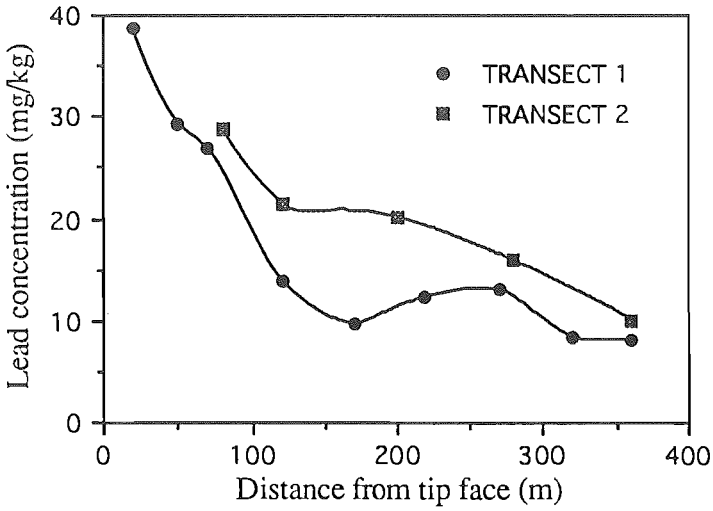

Figure 4: Plot showing the variation in lead concentration in sediment samples as a function of distance from the tip face.

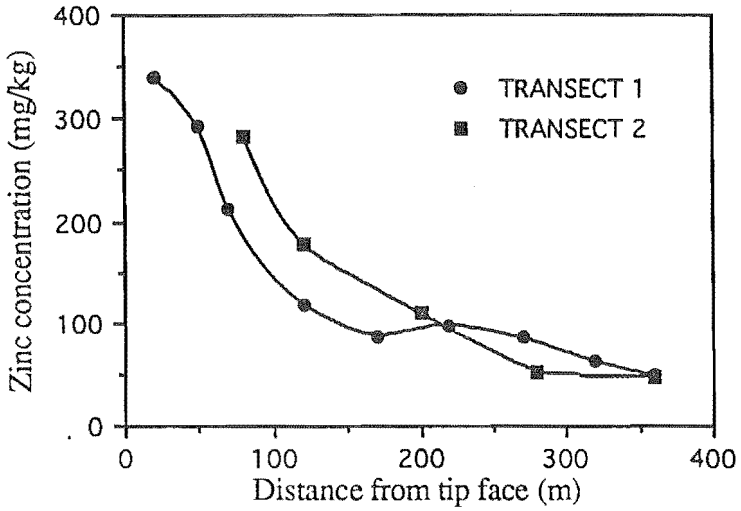

Figure 5: Plot showing the variation in zinc concentration in sediment samples as a function of distance from the tip face.

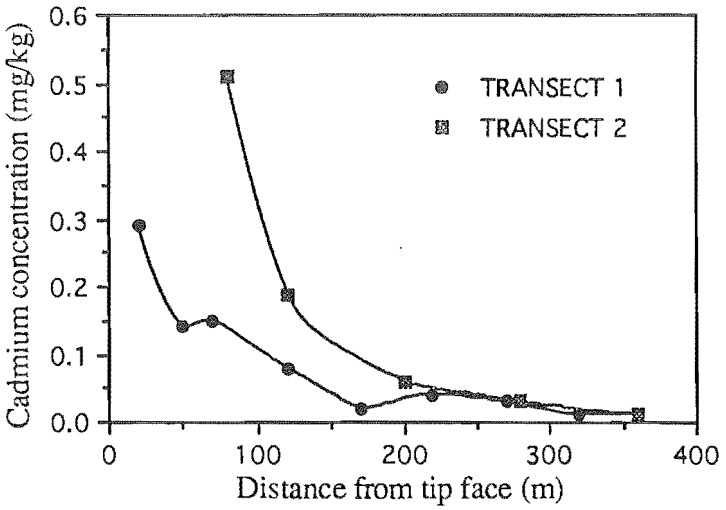

Figure 6: Plot showing the variation in cadmium concentration in sediment samples as a function of distance from the tip face.

TABLE 2

Analytical data for *Avicennia marina* samples

Transect, distance from tip face (m)	Sample type	Age	Tree height (m)	Cu (mg/kg)	Pb (mg/kg)	Zn (mg/kg)	Cd (mg/kg)
1,70	L+			28.41	1.00	48.06	0.04
1,70	B	OY	5	25.58	20.21	80.21	0.08
1,70	F	OY	5	9.37	2.01	35.06	0.02
1,70	L	Y	5	29.36	5.52	53.75	0.02
1,70	W	OY	5	6.56	4.91	33.13	0.03
1,70	B	O	7	25.19	12.56	93.82	0.03
1,70	L	Y	7	23.24	3.92	49.15	0.04
1,70	W	OY	7	10.41	2.73	25.14	0.02
1,120	L+			27.26	1.73	38.06	≤0.01
1,120	B	OY	6.5	19.17	12.09	52.49	0.02
1,120	L	O	6.5	15.74	2.45	27.05	0.02
1,120	W	OY	6.5	8.59	2.13	23.40	0.03
1,170	B	OY	6	17.04	9.95	45.71	0.02
1,170	L	O	6	12.44	2.63	21.50	0.02
1,170	L	Y	6	19.28	2.09	33.84	≤0.01
1,170	W	OY	6	8.08	5.03	22.72	≤0.01
1,220	L+			20.40	1.85	32.12	0.02
1,220	B	O	7	24.98	7.42	35.78	≤0.01
1,220	B	OY	7	18.75	10.16	41.30	0.02
1,220	L	O	7	10.74	1.95	33.93	≤0.01
1,220	L	Y	7	14.90	1.66	38.86	0.12
1,220	W	O	7	9.69	4.71	18.68	≤0.01
1,220	W	OY	7	7.14	3.19	14.06	≤0.01
1,270	L+			16.37	3.33	23.03	≤0.01
1,270	B	OY	9	14.64	10.65	39.86	0.02
1,270	L	O	9	12.36	1.26	14.17	≤0.01
1,270	L	Y	9	13.20	1.22	22.82	≤0.01
1,270	W	OY	9	9.95	3.55	10.76	0.04
1,320	L+			15.13	2.81	26.70	0.02
1,320	B	OY	5	12.87	7.87	33.59	0.03
1,320	L	O	5	9.64	2.10	20.24	≤0.01
1,320	L	Y	5	12.43	1.68	31.41	0.04
1,320	W	OY	5	6.95	3.38	11.58	≤0.01
1,340	B	OY	5	9.14	7.74	42.45	≤0.01
1,340	W	OY	5	2.09	2.02	7.28	≤0.01
1,340	L	O	5	7.21	2.39	12.32	≤0.01
1,340	L	Y	5	10.99	2.07	21.11	≤0.01
1,360	B	O	12	14.52	8.71	38.70	0.03
1,360	B	Y	12	12.95	7.08	33.45	0.02
1,360	F	OY	12	6.73	1.76	20.77	0.03
1,360	L	O	12	7.50	1.71	15.03	≤0.01
1,360	L	Y	12	14.81	3.04	25.56	0.02
1,360	W	O	12	5.33	2.90	8.57	≤0.01
1,360	W	OY	12	4.59	1.23	10.36	≤0.01
2,120	Ltr			32.28	4.56	68.75	≤0.01
2,120	L+			26.70	1.39	41.41	≤0.01
2,120	B	OY	5	23.24	22.60	89.77	0.02
2,120	L	O	5	16.31	1.33	28.59	≤0.01

TABLE 2 contd.

Transect, distance from tip face (m)	Sample type	Age	Tree height (m)	Cu (mg/kg)	Pb (mg/kg)	Zn (mg/kg)	Cd (mg/kg)
2,120	L	Y	5	24.46	0.97	51.14	≤0.01
2,120	W	OY	5	9.41	2.06	33.87	≤0.01
2,120	L	O	5	8.99	3.04	19.27	≤0.01
2,120	L	Y	5	12.40	1.98	46.74	≤0.01
2,200	L+			15.37	1.93	27.68	≤0.01
2,200	B	O	6.5	20.03	16.83	37.49	≤0.01
2,200	B	OY	6.5	26.16	17.67	40.79	≤0.01
2,200	L	O	6.5	9.80	1.41	22.55	≤0.01
2,200	L	Y	6.5	16.51	1.56	42.08	≤0.01
2,200	W	O	6.5	9.93	1.44	12.30	≤0.01
2,200	W	OY	6.5	8.64	2.43	17.74	≤0.01
2,280	L+			12.40	1.07	20.83	≤0.01
2,280	B	OY	5.5	17.41	15.63	42.41	0.04
2,280	L	O	5.5	8.72	2.57	20.27	0.02
2,280	L	Y	5.5	17.13	2.61	29.52	0.02
2,280	W	OY	5.5	10.83	2.65	19.10	0.02
2,360	B	O	14	16.20	12.34	31.62	≤0.01
2,360	L	O	14	7.46	1.65	8.84	≤0.01
2,360	L	Y	14	12.21	1.18	23.71	≤0.01
2,360	W	OY	14	5.17	1.46	9.58	≤0.01
2,360	W	Y	14	7.53	0.77	12.42	≤0.01

In the sample type column, L+ is seedlings, Ltr is leaf litter, F is flowers, B is bark, W is wood, and L is leaf; in the sample age column, O is old, Y is young and OY is used where the age is unknown.

DISCUSSION

There are essentially four ways in which the presence of mangroves can influence the distribution and dispersion of metals:

1. the current baffle provided by mangrove forests aids in the deposition of fine grained sediments which have a greater metal binding capacity that the coarser sediments,

2. sulphate reducing bacteria which commonly colonise the sediment in mangrove forests cause the sediment to become reducing and increase the availability of sulphide ions (both processes help immobilise the common heavy metals),

3. the mangroves incorporate some of the metals into their tissue, and

4. various faunal species which reside in the mangrove forests may take up metals.

Metals influenced by any of these means will be immobilised in the mangrove forest but metals affected by mechanisms 3 or 4 may ultimately be removed from the forest as fauna move into other environments or are consumed by predators which move into other environments and as mangrove debris is washed out of the forest by tidal currents.

Appendix 5 - 10

TABLE 3

Analytical data for species other than *Avicennia marina*

Transect, distance from tip face (m)	Species	Sample type	Age	Tree height (m)	Cu (mg/kg)	Pb (mg/kg)	Zn (mg/kg)	Cd (mg/kg)
1,120	CT	B	OY	3	23.31	7.66	37.38	0.03
1,120	CT	L	O	3	16.15	5.21	32.73	0.02
1,120	CT	L	Y	3	18.59	3.02	24.22	0.05
1,120	CT	W	OY	3	9.68	1.38	19.78	0.02
1,170	CT	B	OY	3	16.38	7.93	25.49	0.02
1,170	CT	L	O	3	14.59	3.57	26.39	0.05
1,170	CT	L	Y	3	15.66	3.11	21.61	≤0.01
1,170	CT	W	O	3	8.70	2.53	11.21	0.04
1,170	CT	W	OY	3	7.42	1.77	16.19	0.03
1,220	AC	B	OY	1.5	12.23	7.90	24.10	≤0.01
1,220	AC	L	O	1.5	8.01	1.04	26.01	≤0.01
1,220	AC	L	Y	1.5	11.23	2.06	33.89	≤0.01
1,220	AC	W	OY	1.5	8.95	2.88	13.58	≤0.01
1,220	CT	B	OY	2	12.89	10.40	23.70	0.04
1,220	CT	L	O	2	8.48	2.11	10.00	≤0.01
1,220	CT	L	Y	2	11.33	1.15	15.24	≤0.01
1,220	CT	W	OY	2	7.85	5.06	21.76	≤0.01
1,270	RS	B	OY	3	15.15	4.87	20.02	0.05
1,270	RS	L+			16.49	2.51	25.69	0.02
1,270	RS	Spr	OY	3	194.71	4.71	355.88	0.06
1,270	RS	W	O	3	9.71	2.52	19.64	0.02
1,270	RS	W	OY	3	10.46	3.84	15.02	0.03
2,200	CT	B	Y	1.5	18.68	15.80	35.12	0.02
2,200	CT	L	O	1.5	6.75	3.35	18.20	0.02
2,200	CT	L	Y	1.5	8.05	8.86	19.18	0.03
2,200	CT	W	Y	1.5	11.96	3.48	18.91	0.02
2,280	RS	B	OY	3	23.70	14.07	37.78	0.02
2,280	RS	L	O	3	13.28	2.79	22.00	0.04
2,280	RS	L	Y	3	19.56	1.63	29.25	≤0.01
2,280	RS	W	OY	3	10.88	2.75	19.42	0.04

In the species column, RS is *Rizophora stylosa*, CT is *Ceriops tagal* and AC is *Aegiceras corniculatum* ; in the sample type column, L+ is seedlings, Spr is a stipule pair, B is bark, W is wood, and L is leaf; in the sample age column, O is old, Y is young and OY is used where the age is unknown.

Mangroves are not as effective at binding sediment as sea grasses because they don't provide a dense vegetation cover near the sediment / water interface, but they do form excellent baffles (particularly species with well developed pneumatophore or stilt root systems) which reduce the flow velocity of any sediment laden currents passing through mangrove forests. The reduction in flow velocity causes an increase in the rate of sediment deposition at the site and a reduction in the vulnerability of existing sediment at the site to scouring and erosion. Consequently, the rate of sediment accretion in mangrove forests is substantially greater than in similar but unforested areas (e.g., Bird, 1971; Chapman, 1977; Stephens, 1962; Hutchings & Saenger, 1987; see also McConchie & Saenger, this volume) and the sediment is usually dominated by the finer grain size fractions. Because particles in the fine clay and silt size fractions have a high charge to mass ratio (e.g., Grim, 1968; Yariv & Cross, 1979), they also have a far greater potential to adsorb metal ions than do coarser sediment particles (e.g., Förstner, 1989; Förstner, & Wittmann, 1981; Luoma, 1990; McConchie, & Lawrance,

1991). Hence, if metal ions are present in surface or groundwaters entering a mangrove forest, the physical properties of the sediment deposited within the forest confer on that sediment a greater capacity to extract metals from solution than exists in coarser sediments outside the forest.

Although sediment particle size alone would make mangrove sediments an effective sink for metals (Harbison, 1986), biogeochemical processes associated with the sediment further enhance its metal storage capacity. In mangrove forests, low energy conditions, muddy organic matter-rich sediments, and a regular supply of sulphate ions, make an ideal environment for sulphate reducing bacteria (e.g., *Desulphiovibrio desulphuricans*). The existence of colonies of sulphate reducing bacteria in mangrove forest sediments is commonly indicated by the presence of highly reducing black sulphidic muds at or just below the sediment surface; similar sediment is also common in marsh land shoreward of the mangrove forest (e.g., the unvegetated zone in Fig. 2). Because many metals, including those examined in this study, are less mobile under reducing conditions and form sulphides with very low solubilities (e.g., Brookins, 1988; Hoffman, 1986), both the sulphide production and the low Eh conditions resulting from the presence of sulphate reducing microbes contribute to the trapping of any metal ions which come in contact with the sediment (Harbison, 1986).

At the Wynnum tip site both the abundance of fine sediments in the mangrove forest and unvegetated zone and the chemical impact of the microbial communities in these muds, contribute to the trapping of any metals which are leached from metallic wastes in the tip. The metal concentration trends in Figs. 3 - 6 are entirely consistent with the trapping of metals from tip leachates by these mechanisms and they also suggest that, with the possible exception of muds adjacent to the tip face, the sediment has the capacity to trap much higher metal loads than have yet been immobilised. Hence, it is evident that these mangrove muds form a very effective trap for any metals which do leach from the tip and thus afford the waters of Moreton Bay some protection from any metals in the tip leachates. However, because the trapping mechanisms depend on the presence of fine grained reducing sulphidic sediment, the trapping effect could easily be reversed (and the metals released) if the mangroves are destroyed or the sediment is drained and allowed to oxidise. Recent data from samples collected during the dry season confirm that the metal trapping can easily be reversed with samples obtained near the sediment surface having lower metal loads than they do during the wet season; during the dry season, the metal concentrations in sediment 50-100 cms below the surface are higher than they are during the wet season. These seasonal changes in metal distribution suggest that some of the metal load is redistributed as the water table rises and falls and hence, that the metal concentration in a sediment sample will depend to some extent on the position of the water table relative to the sampling depth. From an environmental management view point, these observations make a strong case for ensuring that the mangrove belt (Fig. 2) is preserved in its present form and that neither the mangrove belt nor the unvegetated zone are drained. The unvegetated zone could in the future be covered with top soil as part of any land development work, but any lowering of the water table would need to be avoided because the resulting oxidisation of the muds would not only encourage the release of the presently bound metals but would also trigger the formation of acid sulphate soils which would constitute an additional environmental hazard.

The mangrove trees in the belt between the unvegetated zone and the sea show a rise in the concentration of some metals in some plant tissues toward the tip face indicating that the trees themselves contribute to forming the buffer between the tip and the sea. However, the change in metal concentration, in each tissue type, across the forest is less than that evident in the sediments implying that the metal trapping efficiency of the plants is less than that of the sediments they are growing on. Furthermore, because the magnitude of the change in concentration across the mangrove forest differs for each metal, it would appear that the metal concentration in each plant tissue type is not just a function of the metal availability to the plant.

We are not able to form any conclusions about the distribution of cadmium because cadmium concentrations in most types of tissue in most plants were at or near the lower limit of detection for the procedures used; all cadmium concentrations appear to be remarkably low. Lead shows a marked tendency to concentrate in the bark of all the mangrove species

examined, and to a lesser extent in the wood (Tables 2, 3), but only in the bark does the lead concentration increase systematically toward the tip face; the lead content of the wood and leaves changes toward the tip face by less than one standard deviation and the lead content of the seedlings actually shows a small decrease toward the tip.

The concentrations of zinc and copper in all tissue types in the mangroves examined show a small rise (by a factor of about 2 - 3 times) toward the tip except for copper in the wood samples which shows no consistent trend. Both zinc and copper show a tendency to concentrate in the bark, seedlings and young leaves of the mangroves with much lower concentrations being evident in the wood and old leaves. The tendency for seedlings and young leaves to have higher copper and zinc concentrations than old leaves (Tables 2, 3) is unusual because in most organisms the metal load tends to increase with increasing organism age. The data obtained during this study imply that older mangrove leaves are able to reduce their metal load probably as an indirect consequence of the operation of their salt excretion mechanisms. Although we are still investigating this phenomenon, preliminary evidence suggests that because both copper and zinc form highly soluble chloride complexes, some metal is lost as chloride complexes when the mangrove leaves excrete salt; because the salt pumps in young leaves and seedlings are inefficient relative to older leaves, the rate of metal excretion is far greater in older leaves and hence they have lower metal loads. The apparent ability of mature mangrove leaves to excrete some of their metal load means that such plants may be able to tolerate exposure to abnormally high concentrations of metals such as copper and zinc but the same tolerance would not be expected for juvenile plants or young leaves which do not have the same metal excretion capacity.

The mangrove leaf litter (Table 2) analysed from this site, and other litter samples examined during this study, show that on average the mangrove leaf litter contains higher concentrations of most metals than any other part of the plant with the exception of lead in the bark; similar concentration of metals in mangrove leaf detritus has also been found in other studies (e.g., Rice & Windom, 1982). The reason for the high metal concentrations in the litter is unclear but it is clear that if the export of mangrove detritus from the forests by tidal flushing is as high as suggested by Boto & Bunt (1981) then significant amounts of metal may be exported from the mangrove forest in this manner. Some further loss of metals from the mangrove forest may be associated with fauna which take up metals while in the forest and then move into other environments or are consumed by predators which move into other environments. However, for this site, the gradient in metal concentrations in both the sediment and the mangrove plants suggests that net metal uptake within the forest is significantly greater than any metal loss to the sea by biological processes or by any seaward reworking of sediment.

CONCLUSIONS AND IMPLICATIONS

The data obtained in this study indicate that the mangrove forest and the unvegetated zone between the tip face and the forest are forming an effective barrier against the movement of any metallic tip leachates to the waters of Moreton Bay. Metal trapping by the fine grained reducing sulphidic sediments within and shoreward of the mangrove forest probably makes the major contribution to the biogeochemical barrier. However, direct metal uptake by the mangrove plants also traps substantial quantities of copper, zinc and lead. The extent of metal export from the forest is unclear at this stage but it appears to be quantitatively minor.

Recognition of the buffering effect described above and the means by which it operates is significant both scientifically and in terms of its importance to land use planners and environmental managers. In particular, recognition of the major metal trapping capacity of the reducing sulphidic sediments indicates that future land management planning for the area will need to ensure that these sediments are not drained and allowed to oxidise. Oxidisation of the sediments, which would be a likely consequence of any draining of the sediment, would not only release many of the presently trapped metals but would probably also result in the creation of the type of environmental problems typically associated with acid sulphate soil formation.

REFERENCES

Bird, E. C. F., 1971. Mangroves as land builders. *Victoria Natur.*, 88, 189-197.

Boto, K. G., and Bunt, J. S., 1981. Tidal export of particulate organic matter from a northern Australian mangrove system. *Estuar. Coast. Shelf Sci.*, 13, 247-255.

Brookins, D. G., 1988. *Eh - pH diagrams for geochemistry.* Springer-Verlag, N. Y., 176pp.

Chapman, V. J., (Ed.), 1977. *Ecosystems of the World 1: Wet Coastal Ecosystems.* Elsevier, Amsterdam.

Förstner, U., 1989. *Contaminated sediments.* Springer - Verlag, N.Y.

Förstner, U., and Wittmann, G.T.W., 1981. *Metal pollution in the aquatic environment.* Springer - Verlag.

Grim, R. E., 1968. *Clay mineralogy.* McGraw Hill, N.Y., 596pp.

Harbison, P., 1981. The case for the protection of mangrove swamps: Geochemical considerations. *Search*, 12(8), 273-276.

Harbison, P., 1986. Mangrove muds - a sink or source for trace metals. *Mar. Poll. Bull.*, 17(6), 246-250.

Hoffman, S. J., 1986. Soil sampling. In J. M. Robertson (ed.) *Exploration geochemistry: design and interpretation of soil surveys.* Reviews in economic geology, v3, 39-77.

Hutchings, P., and Saenger, P., 1987. *Ecology of mangroves.* University of Queensland Press, 388pp.

Luoma, S. N., 1990. Processes affecting metals concentrations in estuarine and coastal marine sediments. In R. W. Furness and P. S. Rainbow (eds.) *Heavy metals in the marine environment,* CRC Press, 51-66.

McConchie, D. M., Mann, A. W., Lintern, M. J., Longman, D., Talbot, V., Gabelish, A. J., and Gabelish, M. J., 1988. Heavy metals in marine biota, sediments, and waters from the Shark Bay area, Western Australia. *J. Coastal Res.*, 4(1), 51-72.

McConchie, D. M., and Lawrance, L.M., 1991. The origin of high cadmium loads in some bivalve molluscs from Shark Bay, Western Australia: A new mechanism for cadmium uptake by filter feeding organisms. *Archives of Environ. Contam. & Toxicol.* 21, 303-310.

Montgomery, J.R., and Price, M.T., 1979. Release of trace metals by sewage sludge and the subsequent uptake by members of a turtle grass mangrove ecosystem. *Environ. Sci. & Technol.*, 13, 546-549.

Peterson, P. J., Burton, M. A., Gregson, M., Nye, S. M., and Porter, E. K., 1979. Accumulation of tin by mangrove species in West Malaysia. *Science of the Total Environment,* 11, 213-221.

Rice, D. L., and Windom, H. L., 1982. Trace metal transfer associated with the decomposition of detritus derived from estuarine macrophytes. *Bot. Mar.*, 25, 213-223.

Saenger, P., Specht, M.M., Specht, R.L., and Chapman, V.J., 1977. Mangal and coastal saltmarsh communities in Australasia. In: Chapman, V. J. (Ed.), *Ecosystems of the World. I. Wet Coastal Ecosystems.* Elsevier, Amsterdam, pp. 293-345.

Stephens, W. M., 1962. Trees that make land. *Sea frontiers,* 8, 219-230.

Thomas, C., and Eong, O. J., 1984. Effect of heavy metals zinc and lead on Rhizophora mucronata Lam. and Avicennia alba Bl. seedlings. *Proc. As. Symp. Mangr. Env. Res. Manag.*, 568-574.

Walsh, G. E. R., Ainsworth, K. A., and Rigby, R., 1979. Resistance of red mangrove (Rhizophora mangle L.) seedlings to lead, cadmium, and mercury. *Biotropica,* 11(1), 22-27.

Yariv, S., and Cross, H., 1979: *Geochemistry of colloid systems for earth scientists.* Springer-Verlag, N.Y.

Appendix 5 - 14

To Whom it may concern,

Malcolm Clark has contributed to the production of this paper by supplying all of the figures used and all of the data used to construct figure 2; data collected for figure 2 represents part of the data collected for the construction of the contour maps used in his thesis. Malcolm also made a significant contribution to the interpretation of the data and development of the scientific ideas on which the paper is based.

Yours sincerely